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Final Report

FIN ANIMAL ANTENNA

Contract No: NAS5-11689

Prepared by

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Falls Church, Virginia 22041

for

Goddard Space Flight Center
Greenbelt, Maryland 20771

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Goddard Space Flight Center
Contracting Officer: N. Mignone
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July 1970

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SUMMARY

A fin antenna has been developed to operate with the IRLS system to provide optimum patterns for animal packages when interrogated from a satellite. The antenna has a pattern which maximizes the energy radiated near zenith. The antenna is circularly polarized. One of the primary characteristics of the antenna is its rugged, low-profile mechanical design.

The work performed during the antenna development is described. The results obtained are close to or exceed the design goal in all respects. The characteristics of the final model are described.

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1.0 INTRODUCTION

This report is prepared under Contract No. NAS5-11689 to document the development work undertaken to establish the electrical parameters of a fin that would best optimize the performance of the antenna in terms of pattern, polarization and size.

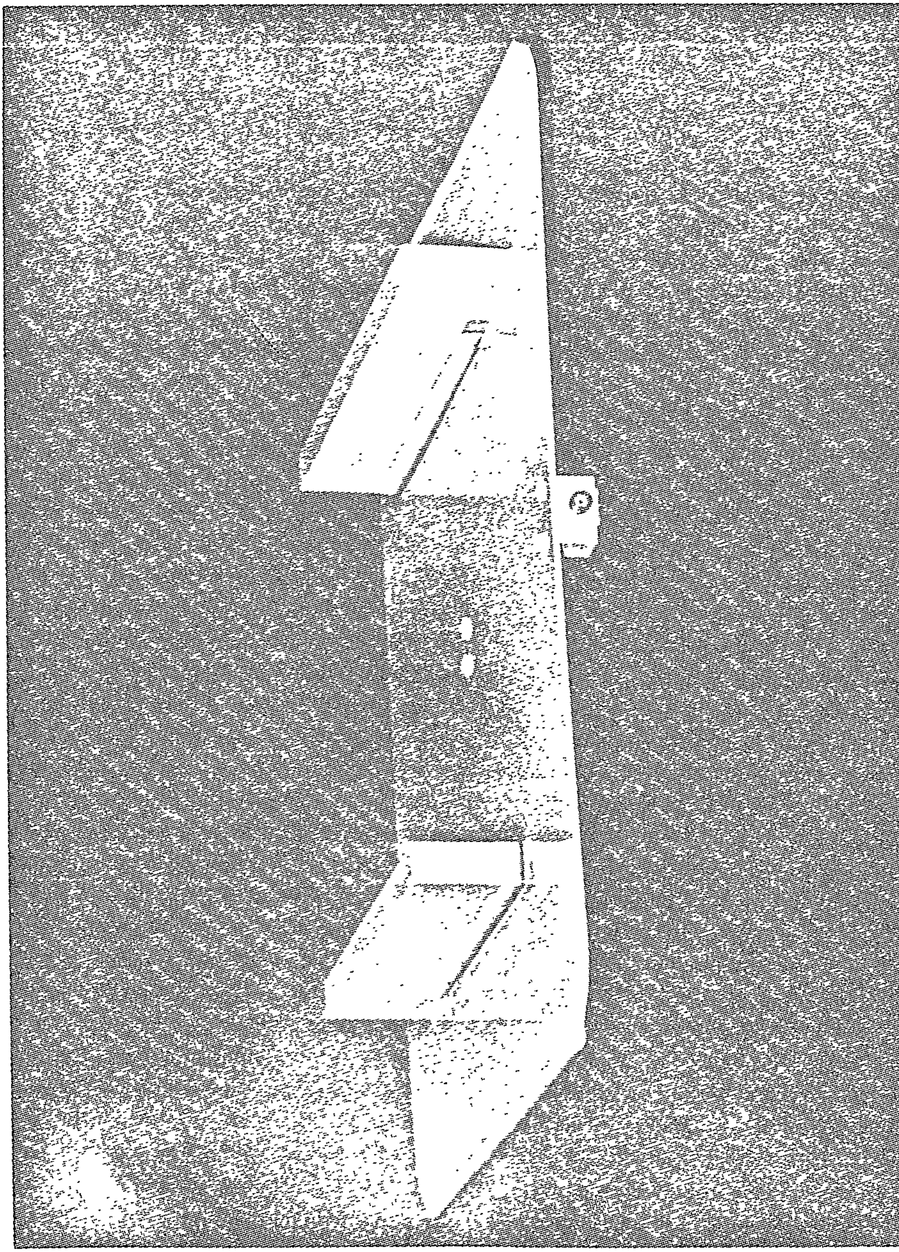
The antenna is designed to operate with an instrument package mounted on a collar around the neck of an animal. It is interrogated by the IRLS system on a spacecraft. The antenna operates at 401.5 MHz and 466 MHz.

It is desired to achieve the best possible impedance match to a 50 ohm coaxial input with a design goal VSWR of 1.3. The antenna pattern should maximize the power radiated near zenith, have minimum groundplane and antenna size, and be circularly polarized (right hand) with good axial ratio. The antenna should be moisture proof over extended periods of time and be capable of handling a peak power of ten watts.

The antenna developed under this contract is optimized for the application. The gain is 2db. or more at both frequencies and the VSWR is less than 1.3.

This report describes the experimental work in chronological order. Patterns were measured for approximately thirteen configuration. The discussion is not confined to the work which produced good results. Some things were tried which did not work, and these are included for the benefit of future investigations.

This report concludes with a summary of the results obtained on the final engineering model antenna. Figure 1 is a photograph of this antenna.



NOT REPRODUCIBLE

Figure 1. Photograph of First Engineering Model Fin Animal Antenna

2.0 ELECTRICAL DEVELOPMENT

This section describes the experimental work in the order in which it was performed. Tasks that produced negative results are included with tasks that produced positive results. Patterns were measured for approximately thirteen configurations shown in Table 1. These include a single fin, a fin with a folded transmission line, a fin on a slotted groundplane, a Vee fin, a double fin, and the final engineering model. The following sections describe these configurations and the results obtained therefrom.

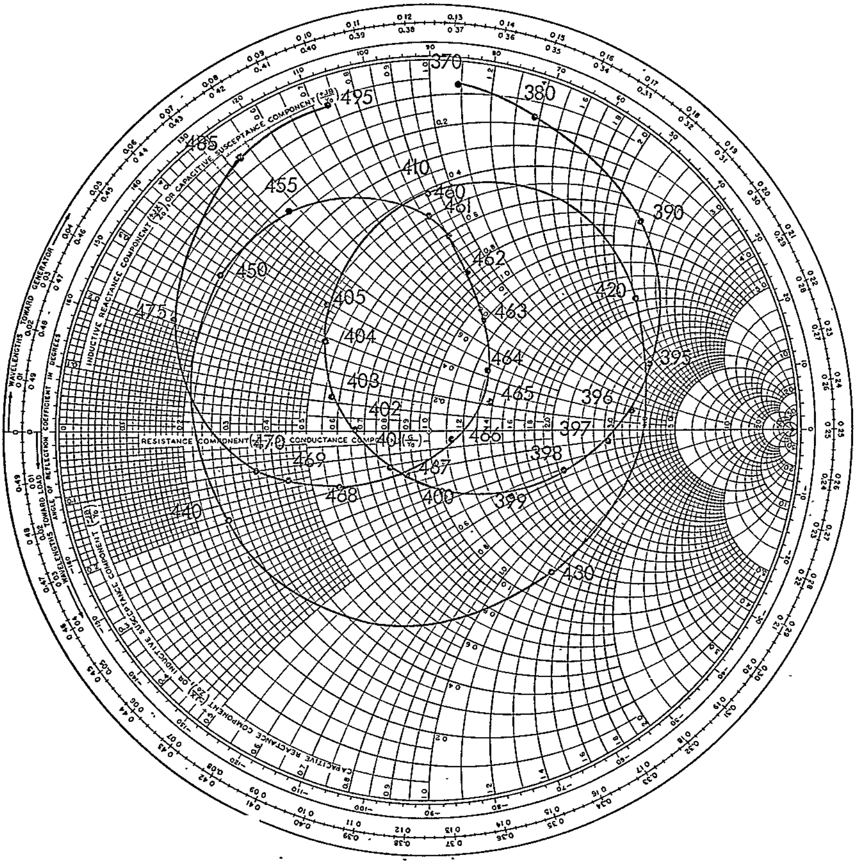
2.1 Single Fin

A single fin antenna was selected first because of its inherent advantage as a compact, rugged low-profile circularly polarized antenna. The antenna is required to operate at frequencies of 401.5 MHz and 466 MHz, two frequencies separated by approximately fifteen percent. The fin antenna itself is inherently a narrow ban device with a bandwidth of approximately two percent. It was therefore necessary to devise a special matching circuit to match the single fin antenna at the two frequencies. This was done with some difficulty and the Smith chart plot is shown in Figure 2. Note the VSWR is less than 1.8:1 from 399 to 403 MHz and from 466 to 468 MHz. The VSWR is about 1.3:1 at 401.5 MHz and 466 MHz. The impedance of Figure 2 may not be optimum but it demonstrates that it is possible to match the antenna reasonably well at the two operating frequencies. Patterns for the double tuned antenna are shown in Figure 3 through 8. The fin was used as a receiving antenna for these patterns.

No.	Configuration	Groundplane size	Figure Numbers
1.	Single doulbe-tuned fin	10"x14"	2-8
2.	Single fin	28"x28"	9-11
3.	Fin with folded transmission Line-foam dielectric	10"x14"	12-14
4.	Fin with folded transmission Line-foam and teflon	10"x14"	15-20
5.	Fin with folded transmission Line-opposite side shorted	10"x14"	21-22
6.	Fin with folded transmission Line-Barrier on opposite side	10"x14"	23-25
7.	Fin on slotted groundplane	10"x14"	26-28
8.	Fin with parasite fin	10"x14"	29-44
9.	Vee fin	10"x14"	45-52
0.	Vee Plus fin	10"x14"	53
1.	Right angle fins	10"x14"	54-55
12.	Double fin, single-tuned	10"x14"	56-65
13.	Double fin, dual frequency	10"x14"	66-71

Table I Fin Antenna Configurations

Numbers on curve are frequency in Megahertz



Yo= 1/50 Ω

Figure 2. Double Tuned Fin Admittance

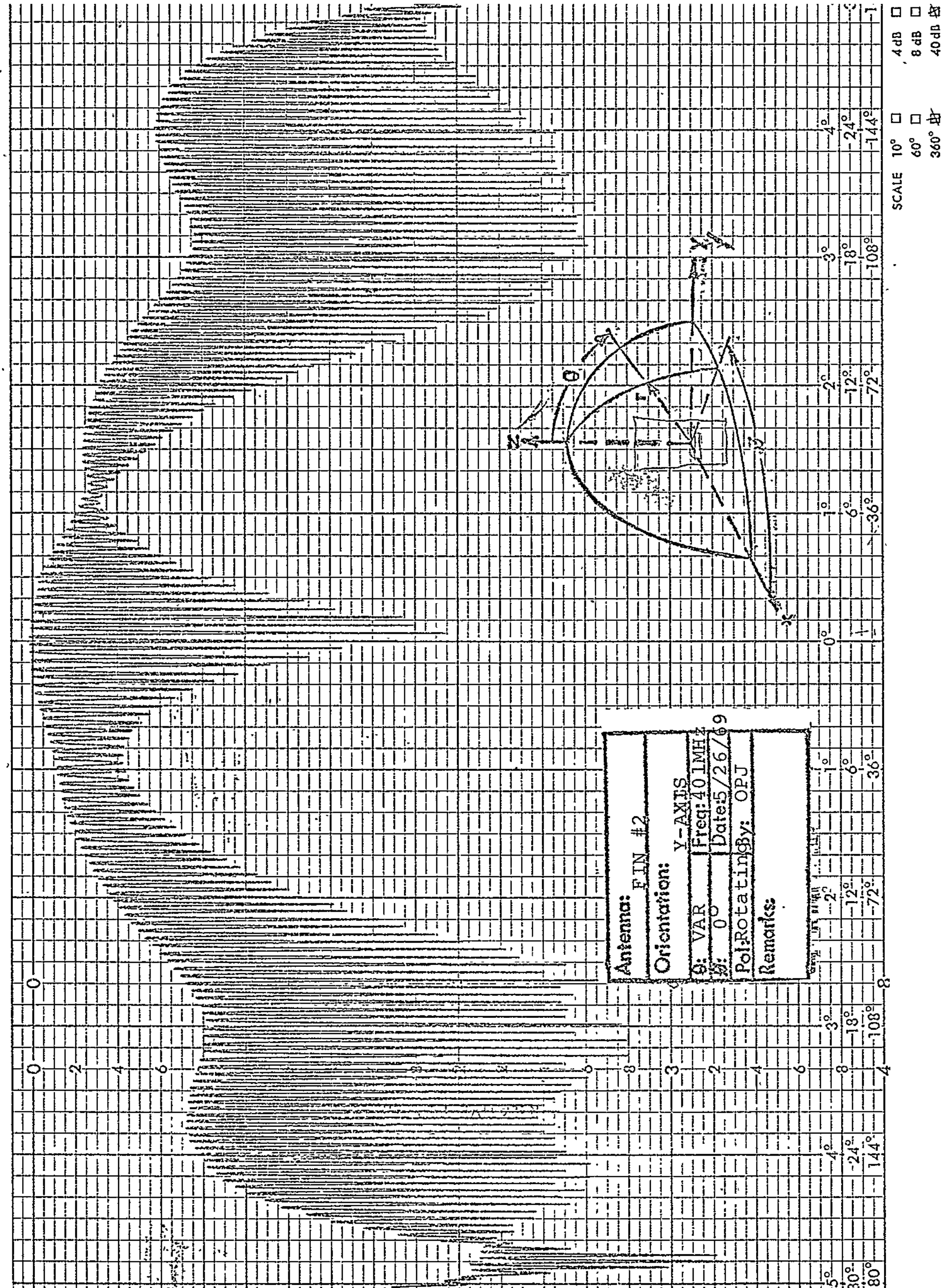


Figure 3. Double Tuned Fin Pattern, $\phi=0°$, Rotating Polarization, 401 MHz

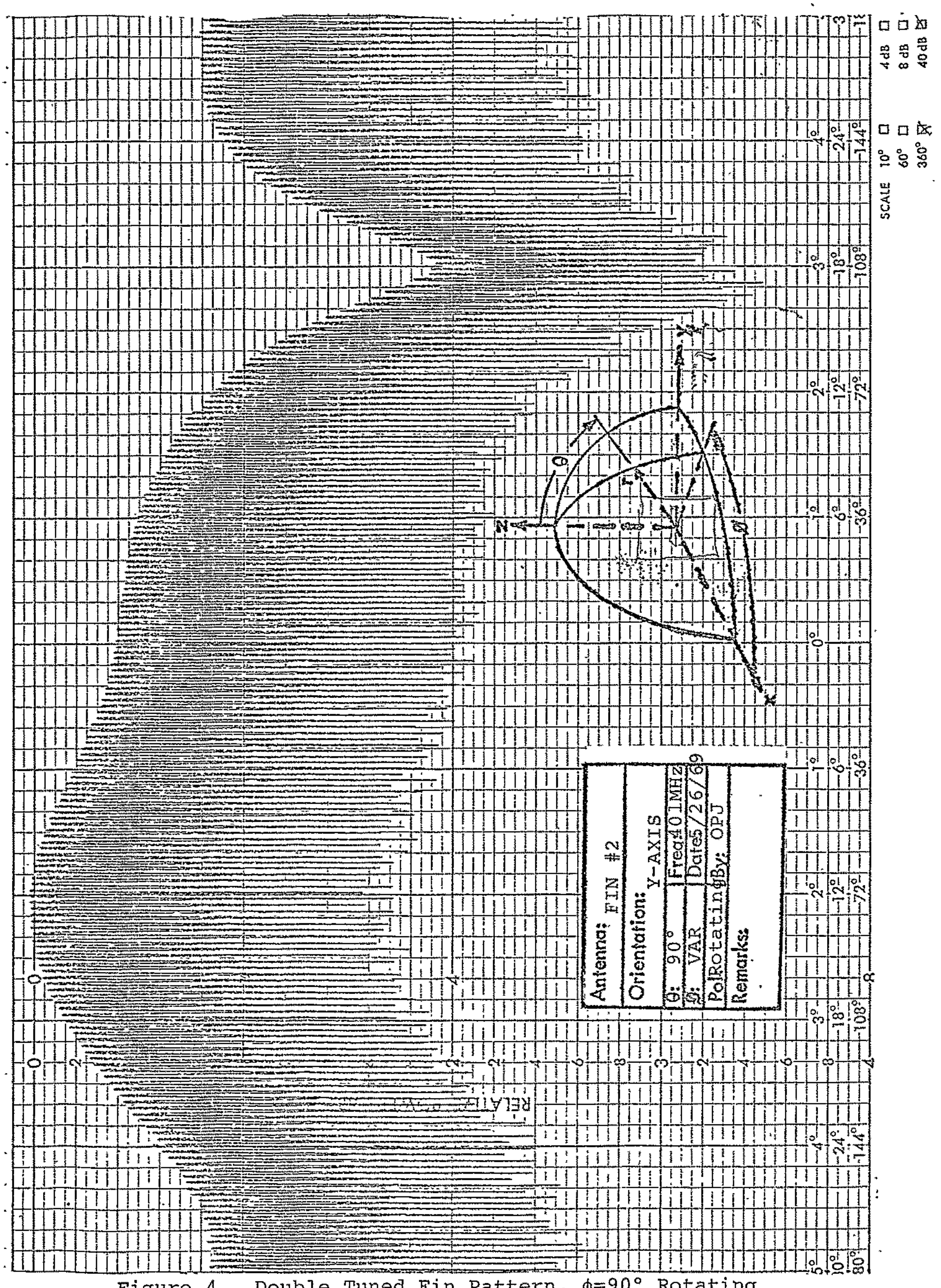


Figure 4. Double Tuned Fin Pattern, $\phi=90°$ Rotating Polarization, 401 MHz

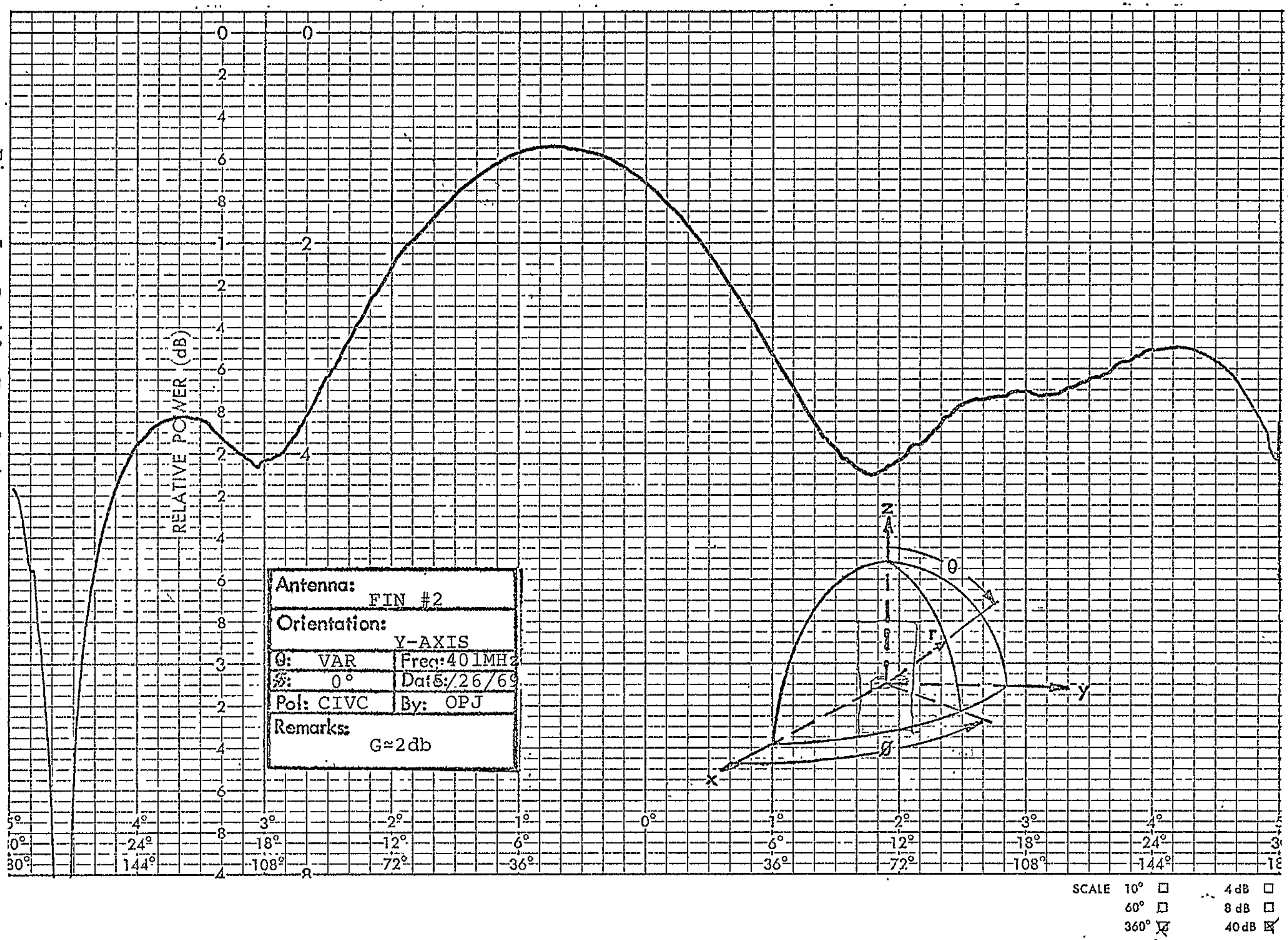


Figure 5. Double Tuned Fin Pattern, ϕ=0°, Circular Polarization, 401 MHz

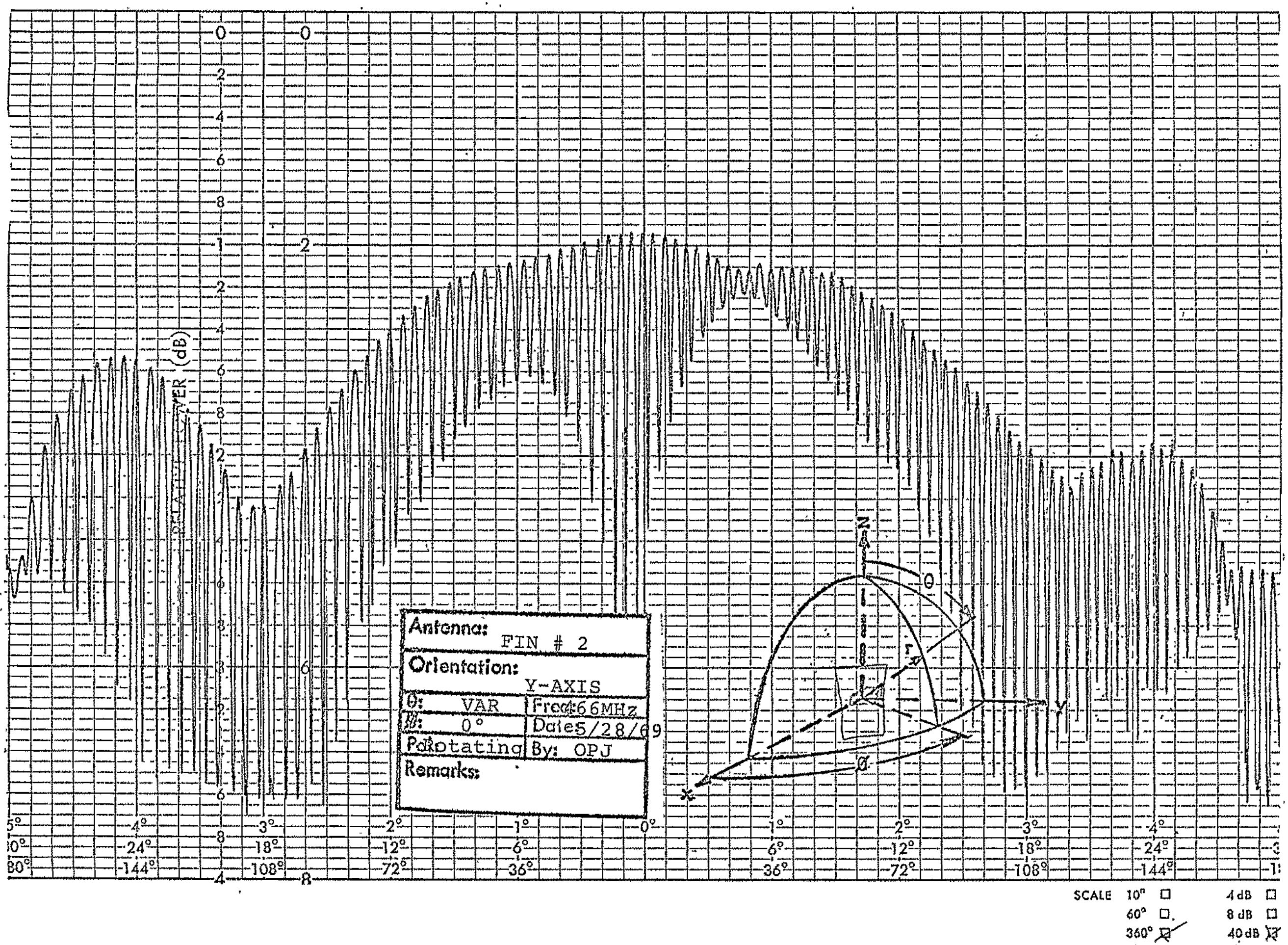


Figure 6. Double Tuned Fin Pattern, φ=0°, Rotating Polarization, 466 MHz

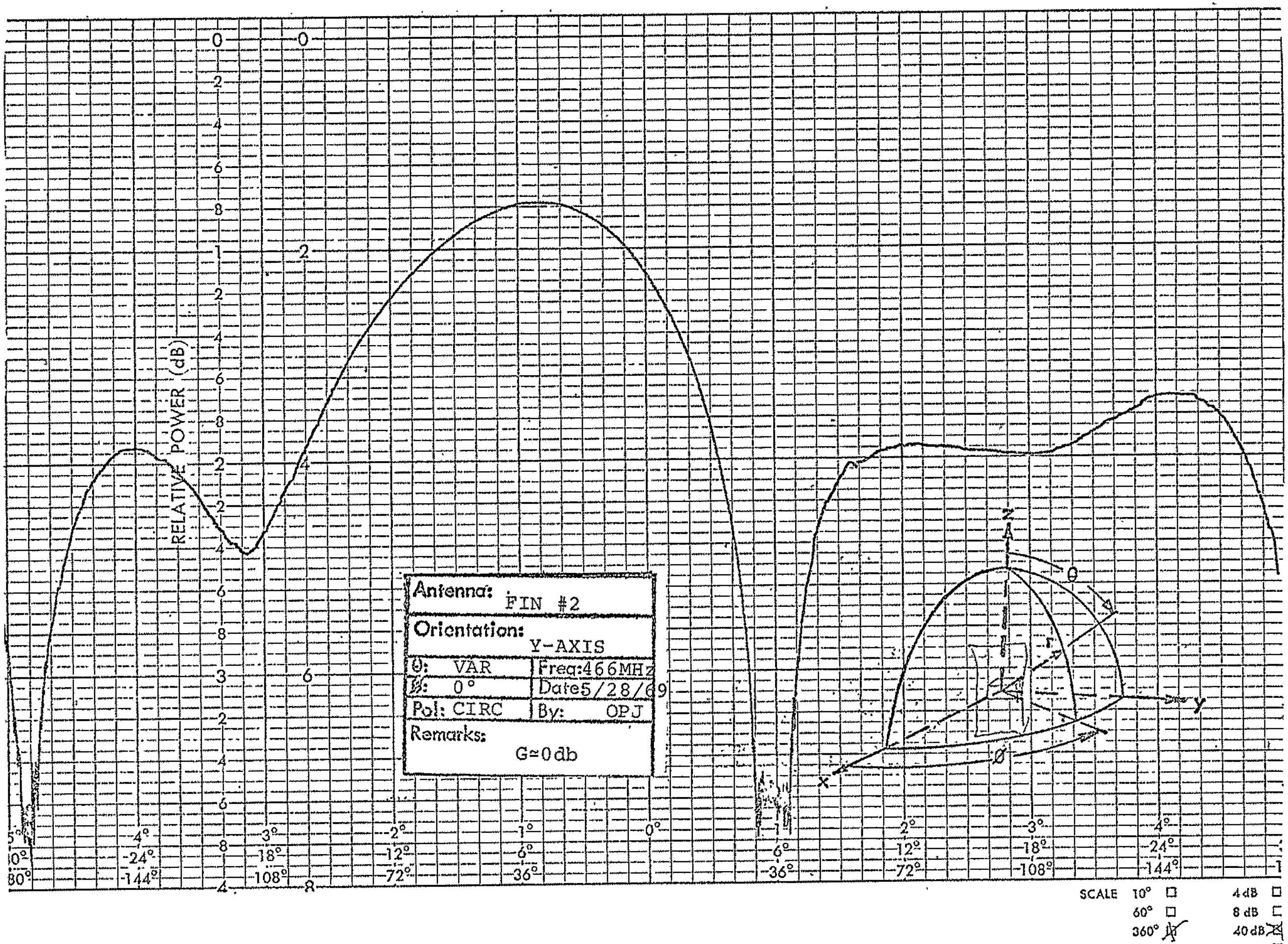


Figure 7. Double Tuned Fin Pattern, φ=90°, Circular Polarization, 466 MHz

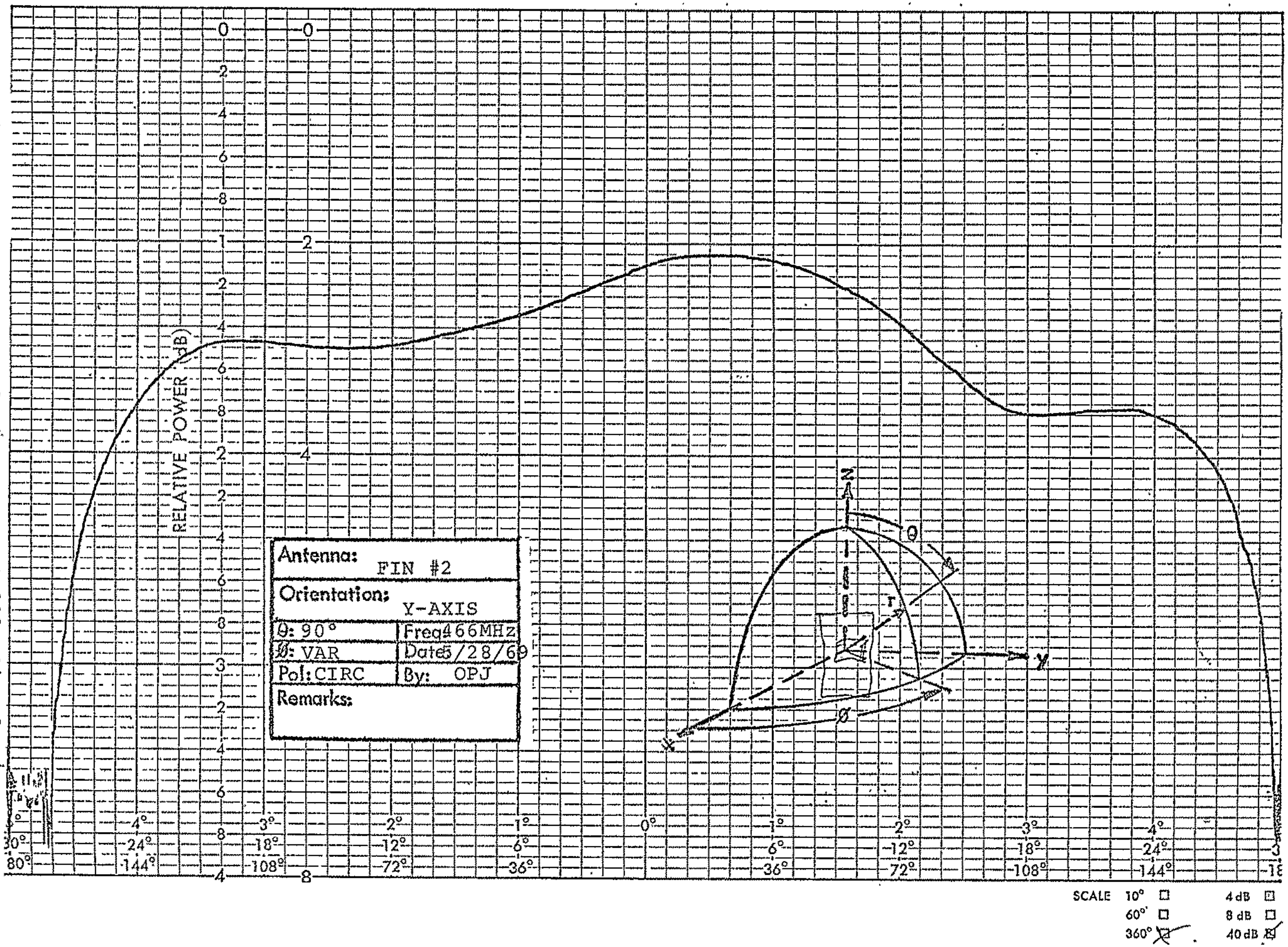


Figure 8. Double Tuned Fin Pattern, ϕ=90°, Circular Polarization, 466 MHz

The patterns of Figures 3 through 5 were measured at 401 MHz and the others were measured at 466 MHz. The patterns of Figures 3, 4 and 6 were measured with the illuminating polarization linear and rotating and the others were measured with right hand circular polarization illumination. The patterns of Figures 3, 5, 6 and 7 were taken in a plane perpendicular to the planes of the fin and the groundplane and the others were taken in the plane of the fin.

The patterns are typical of those obtained for fin type antennas. They show essentially linear polarization in the plane of the fin and relatively circular polarization (axial ratio less than six db.) over two 45 degree sectors on either side of the fin.

Circular polarization is obtained because the feed system excites both the slot and the fin. From Maxwell's equations, the slot field is 90° out of phase with the fin field. This 90° displacement in space and phase produces the circular polarization. Separate horizontally and vertically polarized patterns confirm that the zero db axial ratio occurs when thes two fields are equal. The geometry of the fin indicates the circular polarization direction is orthogonal on the opposite sides of the fin which is confirmed in Figures 5 and 7.

The gain of the double tuned fin antenna was measured to be 2db. at 401 MHz and 0 db at 466 MHz. The poor match at 466 MHz caused a 1db. loss due to the reflection, so the gain at 466 MHz when matched should be 1 db.

This fin antenna was delivered to the Goddard Space Flight Center and connected to the IRLS platform for use with the Nimbus spacecraft. Satellite signals which were identifyable (but weak) were received at a slant range of 3000 kilometers, but platform hardware problems prevented the up link from working properly.

An examination of the patterns of Figures in 5 and 7 shows a right-hand circularly polarized beam displaced from the zenith with a relatively sharp 15 to 25 db null on one side 36° from from zenith. A study was made to determine whether a larger groundplance would markedly improve the pattern. The groundplane was increased in size from the original 10" by 14" to 28" square. The patterns obtained from this larger square groundplane are shown in Figures 9 through 11. The performance of this antenna with a larger groundplane was substantially the same as the performance of the antenna with the smaller groundplane.

This pattern null and the relatively poor performance in working with the satellite lead to an extensive development

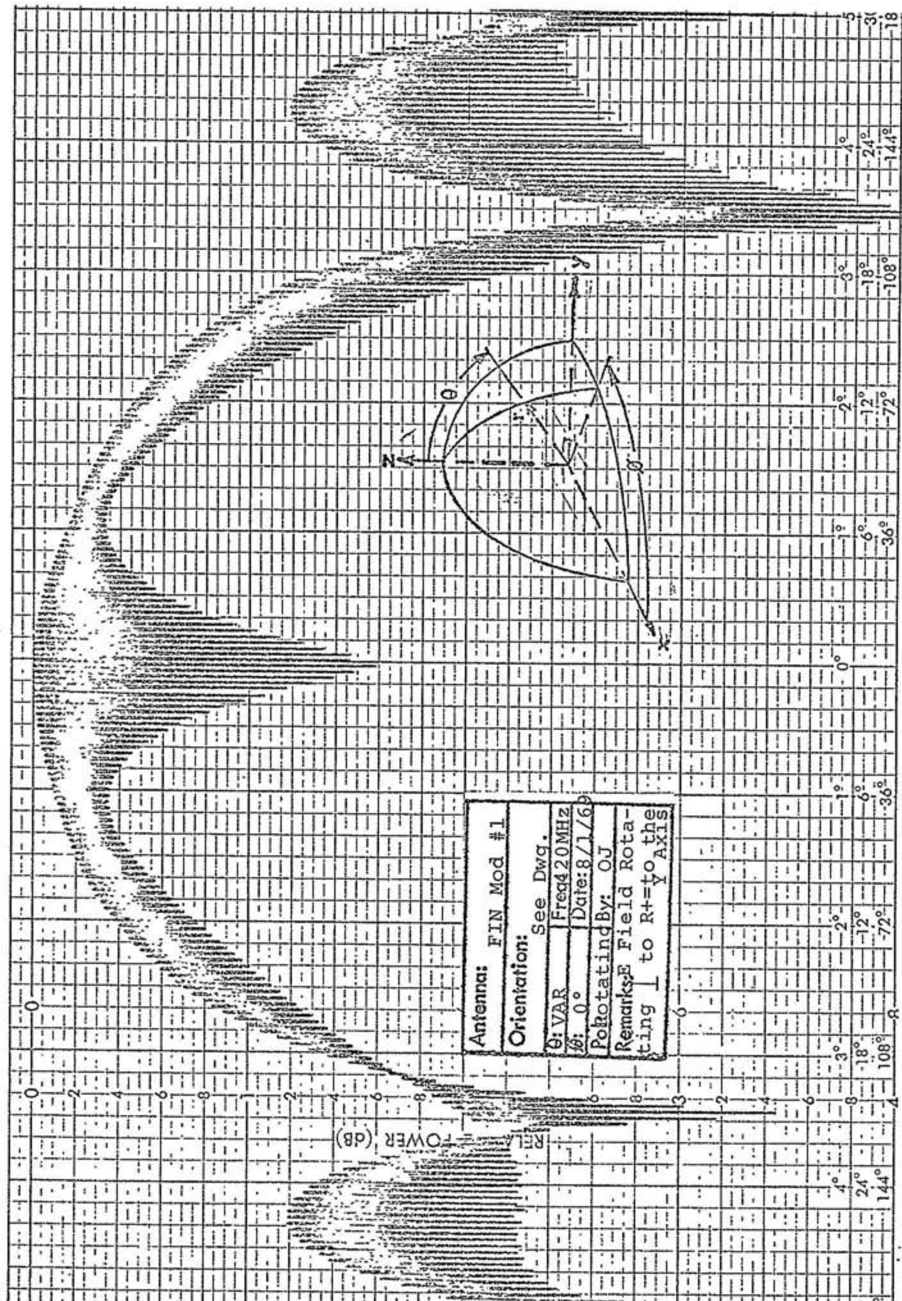


Figure 9. Pattern For Large Groundplane, ϕ=0°, Rotating Polarization

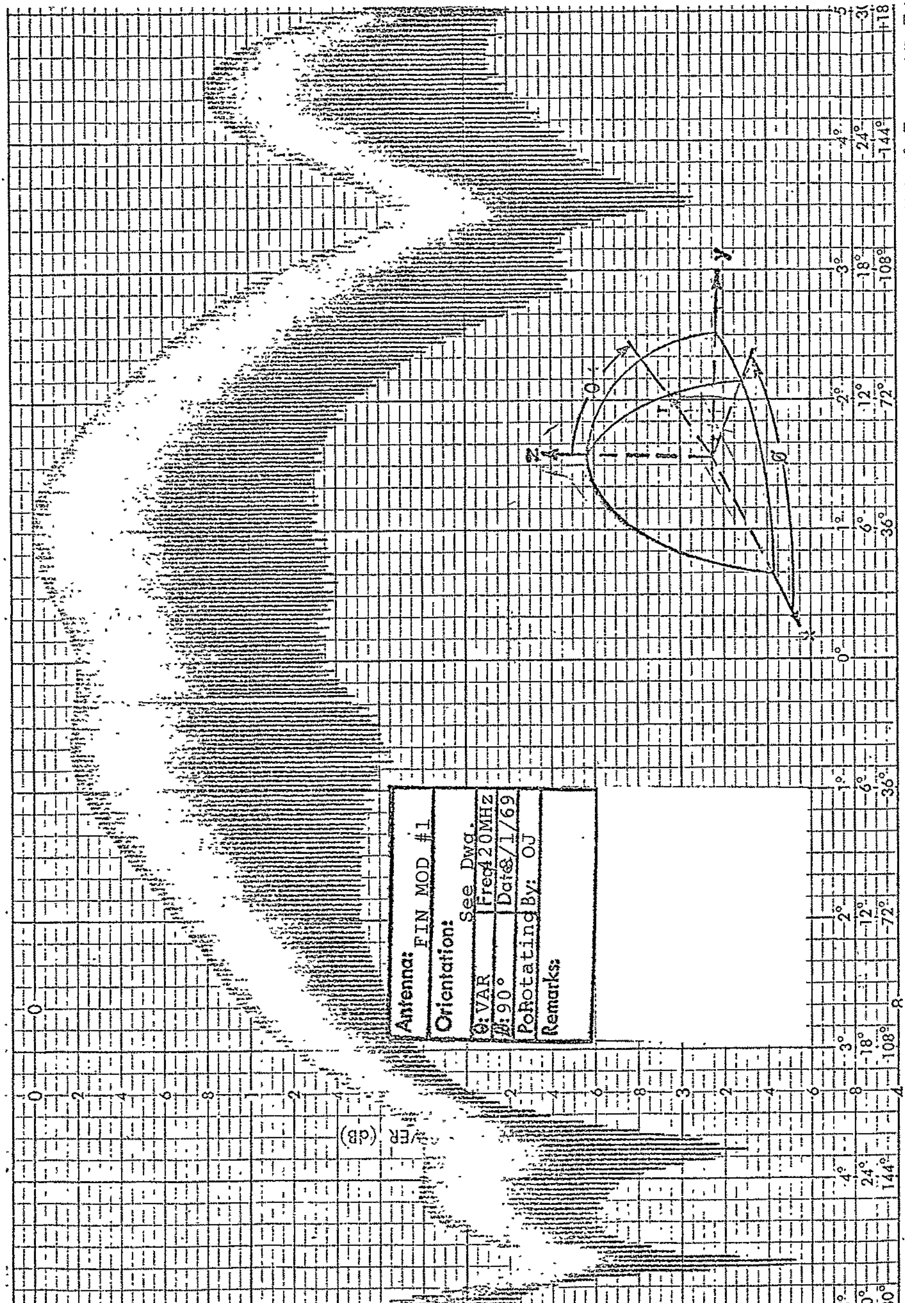


Figure 10. Pattern For Large Groundplane, $\phi=90°$, Rotating Polarization

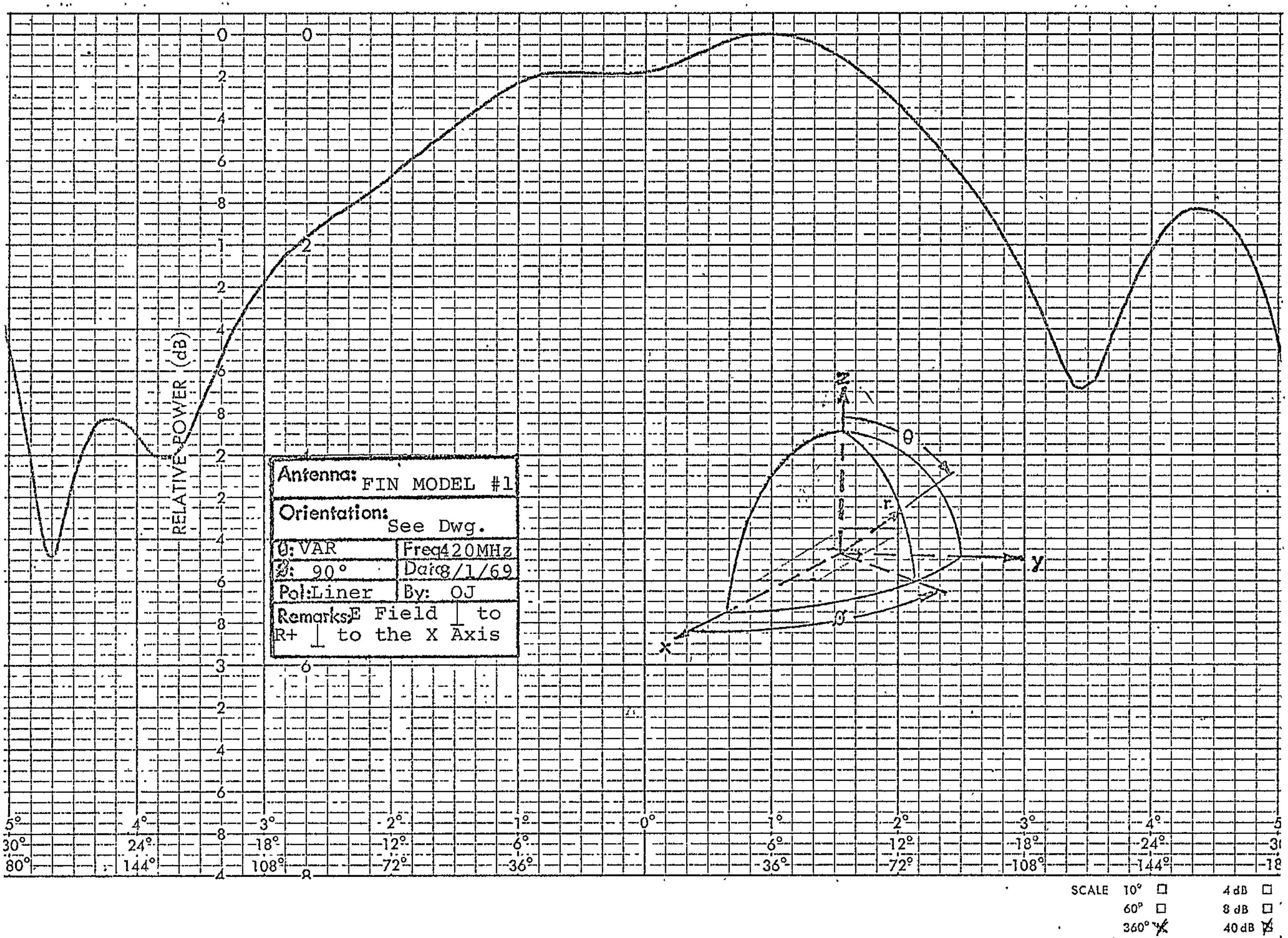


Figure 11. Pattern For Large Groundplane, $\phi=90°$, Y-Axis Polarization

program to obtain an antenna with better overhead coverage. The details of the various antennas which were built and tested in the experimental program are given in the following sections.

2.2 Fin with Folded Transmission Line

The fields from the currents on the fin in the voltage across the slot add on one side of the fin to produce right-hand circular polarization and add on the other side of the fin to produce left-hand circular polarization. An attempt was made to add a half-wavelength transmission line on one side of the fin slot in the hope that the energy radiated into this extra length would be shifted in phase and add with the energy from the other side of the fin to produce right-hand circular polarization on both sides of the fin. A sketch of this configuration is shown in Figure 12. The transmission line was initially foam filled and open on the end where the fin was open. Patterns for this configuration are shown in Figures 13 and 14. The axial ratio for this antenna is not particularly good but the circularly polarized antenna pattern of Figure 14 shows good symmetry about the zenith angle. Unfortunately this antenna had a gain of approximately -15 db and was therefore unacceptable.

There was some concern about the phase of velocity in the folded transmission line and the possibility that the line length was not exactly a half wavelenght. Therefore several of the foam spacers were replaced by teflon spacers to increase the electrical

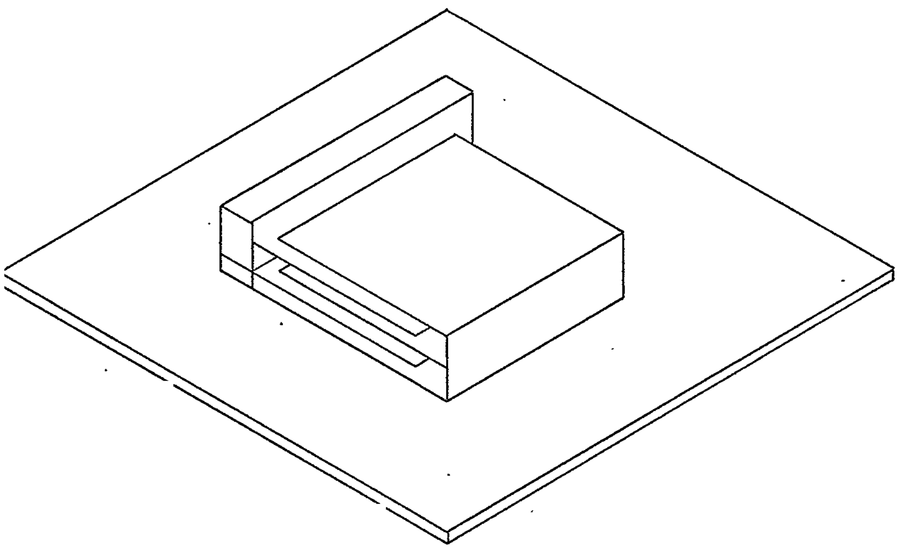


Figure 12. Sketch of Fin With Folded Transmission Line

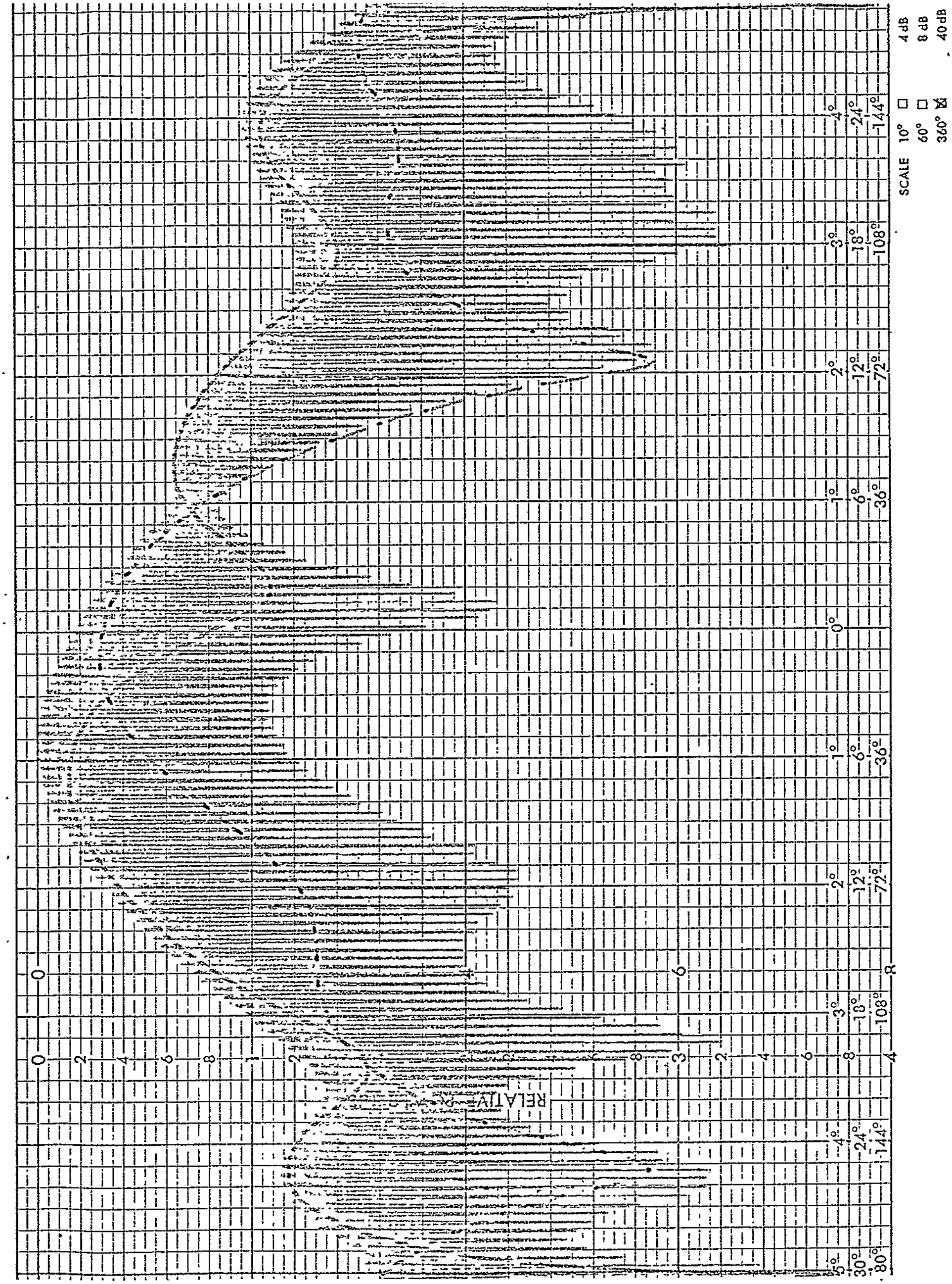


Figure 13. Pattern For Fin With Foam Dielectric Transmission Line, Rotating Polarization

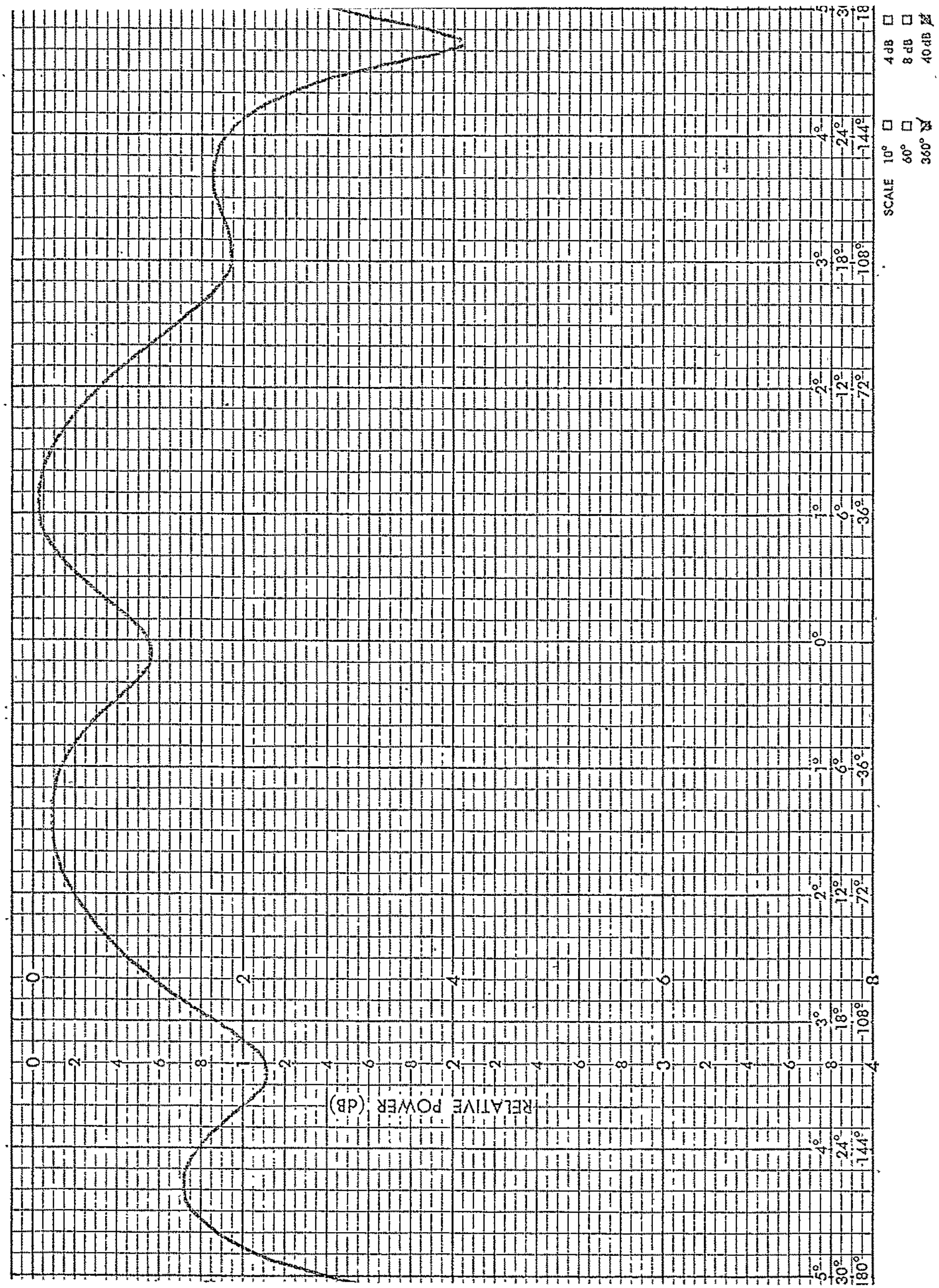


Figure 14. Pattern For Fin With Foam Dielectric Transmission Line, Circular Polarization

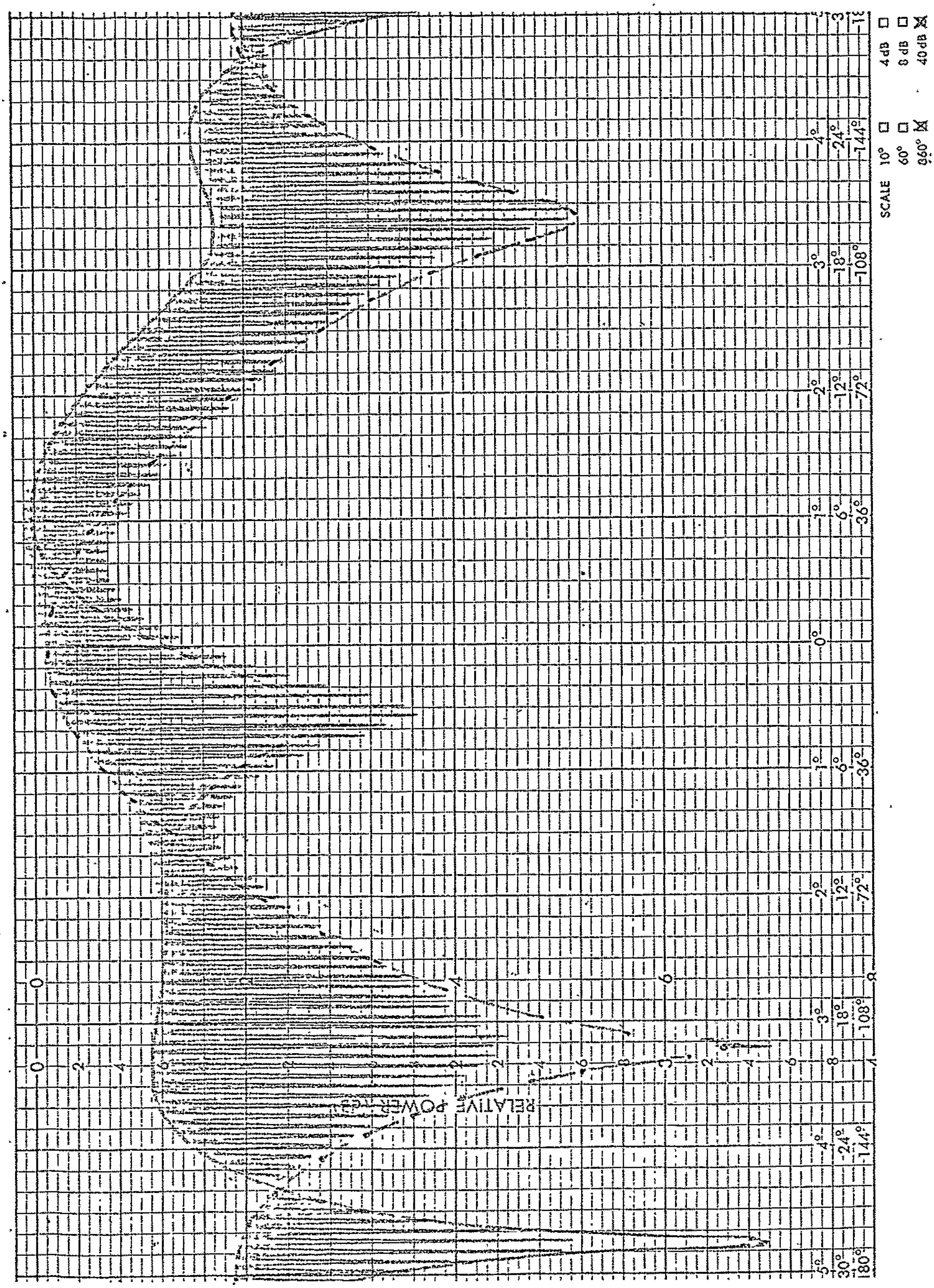


Figure 15. Pattern For Fin With Foam and Teflon Dielectric
In Transmission Line, Rotating Polarization

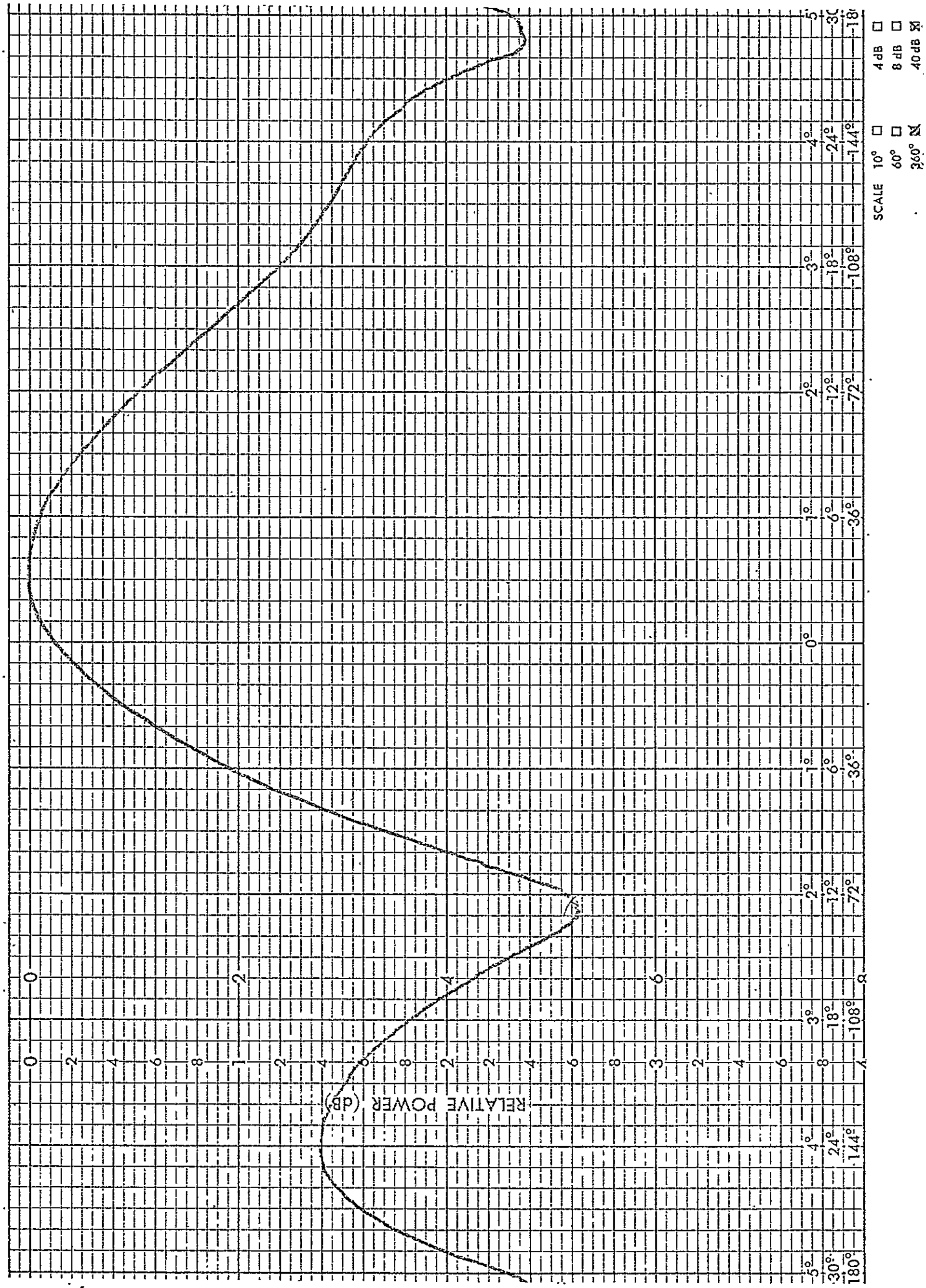


Figure 16. Pattern For Fin With Foam and Teflon Dielectric In Transmission Line, Circular Polarization

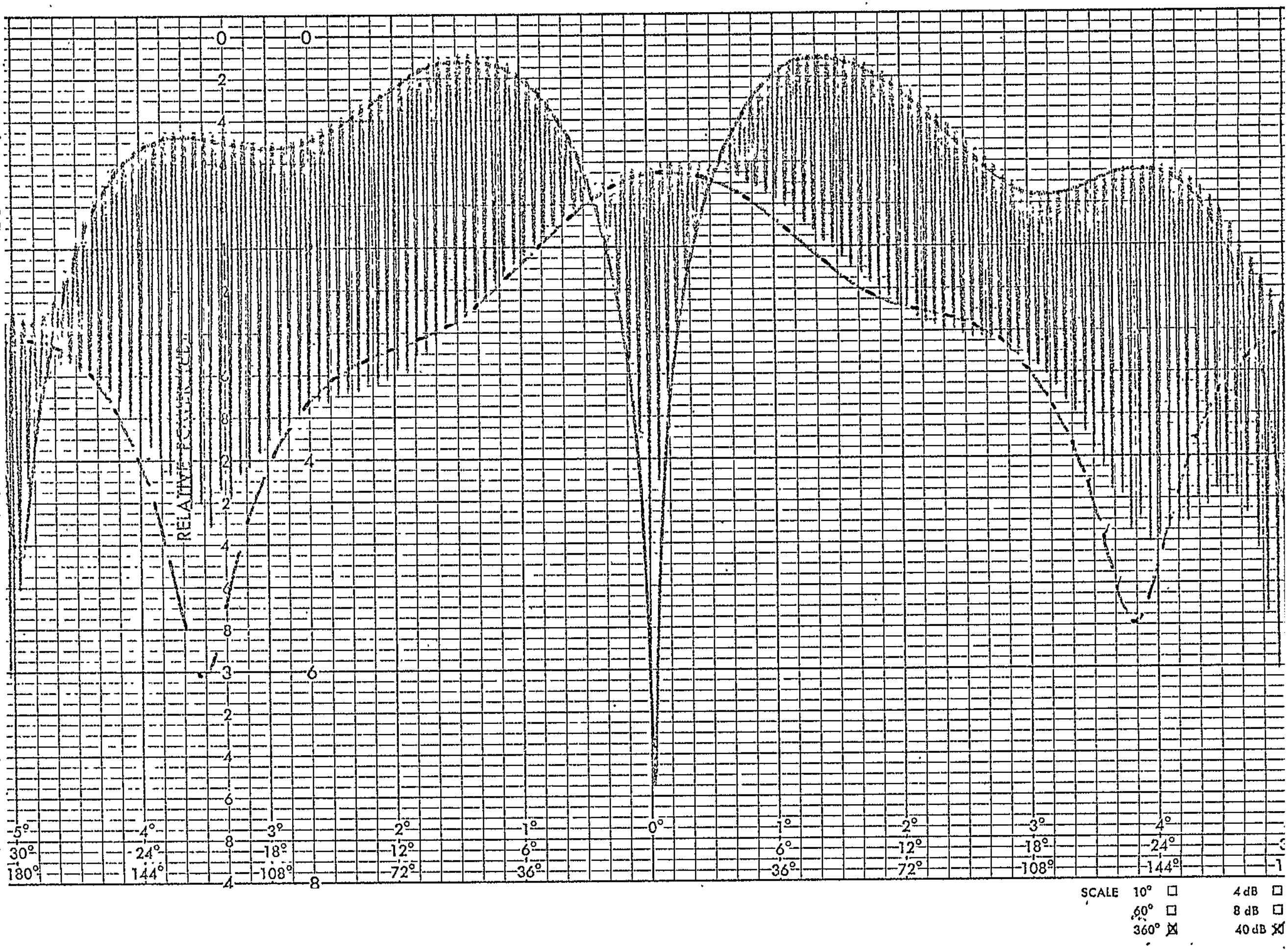


Figure 17. Pattern For Fin With Foam and Teflon Dielectric
In Transmission Line, Rotating Polarization

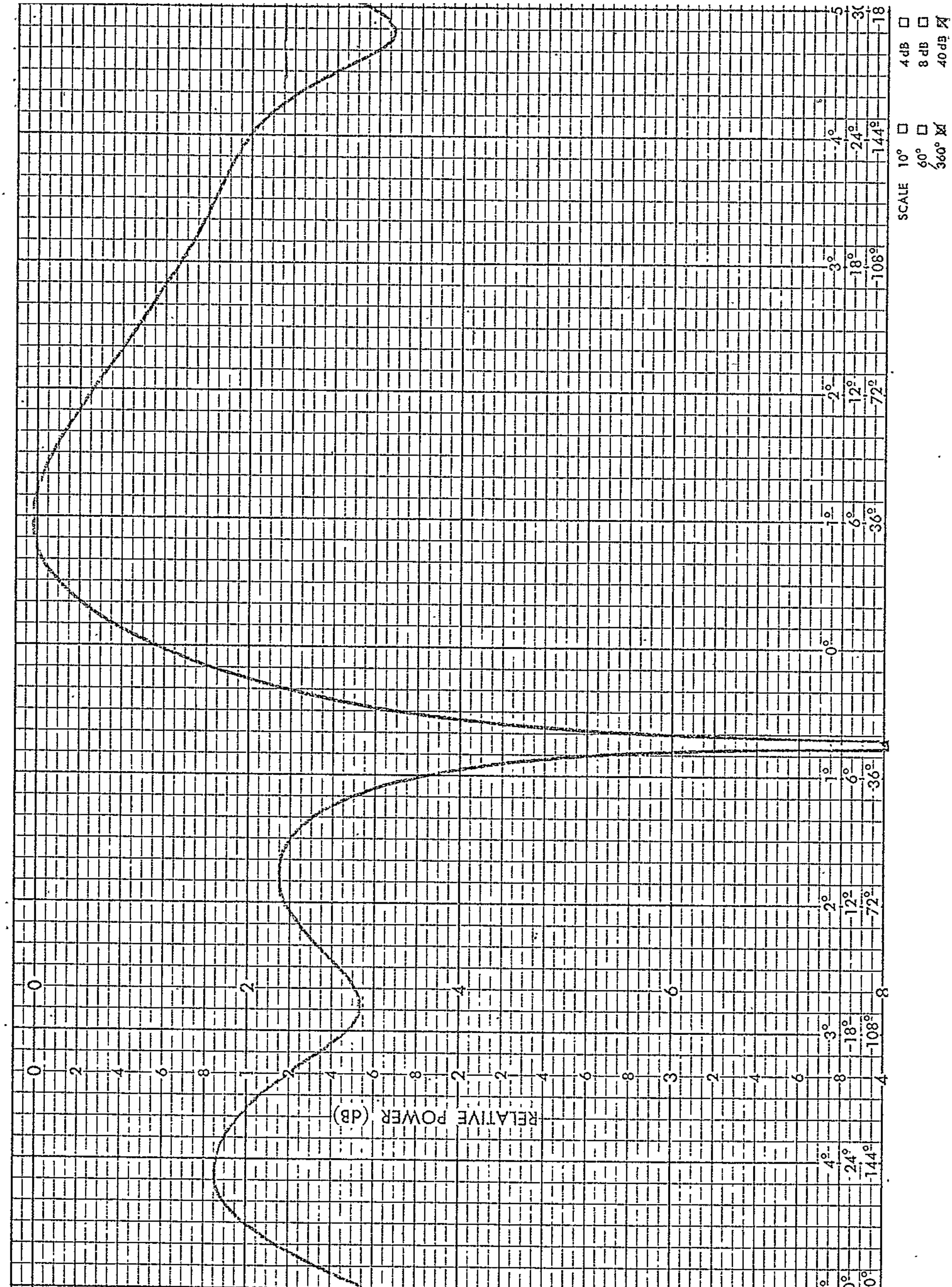


Figure 18. Pattern For Fin With Foam and Teflon Dielectric In Transmission Line, Circular Polarization

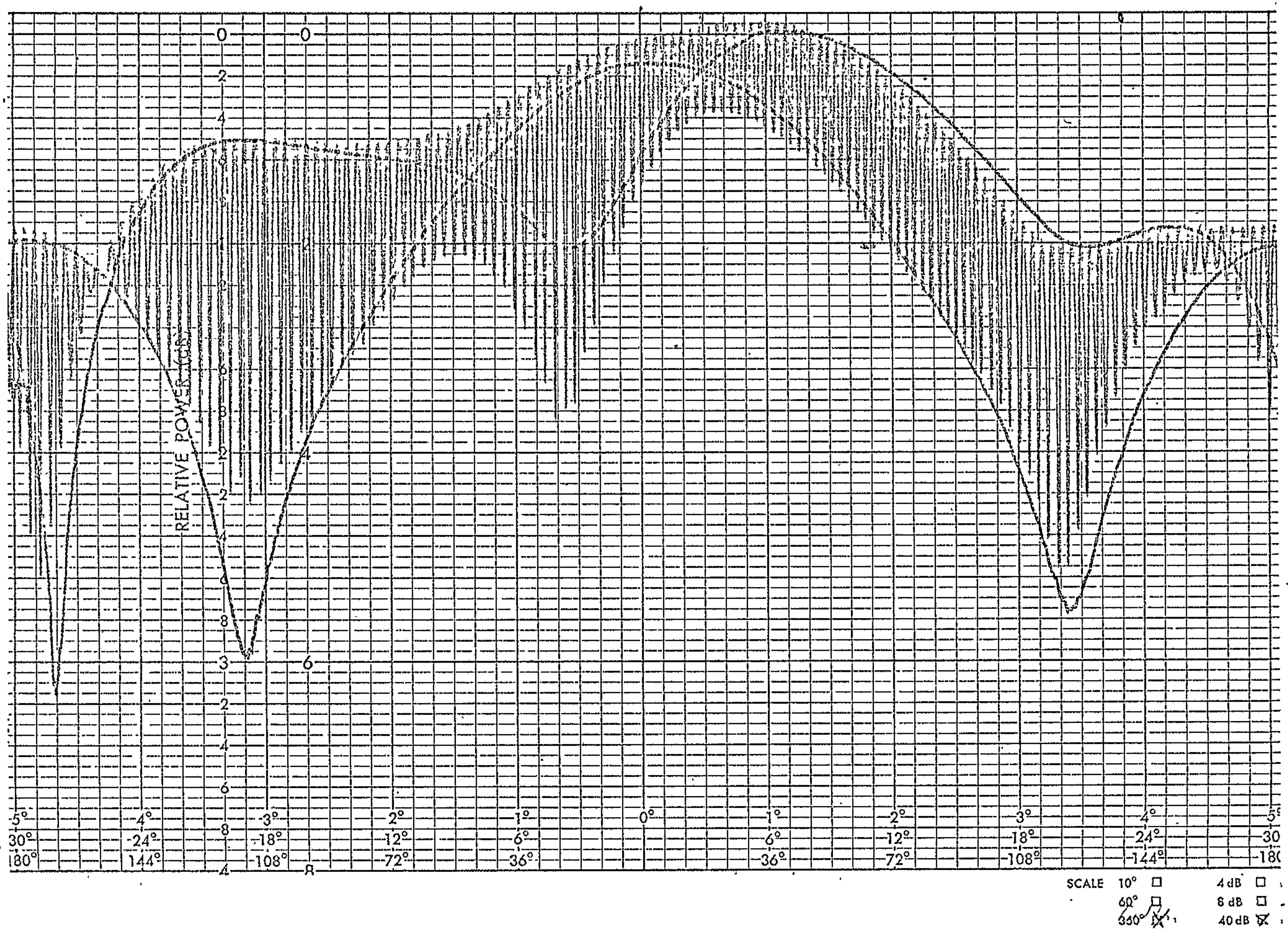


Figure 19. Pattern For Fin With Foam and Teflon Dielectric In Transmission Line, Rotating Polarization

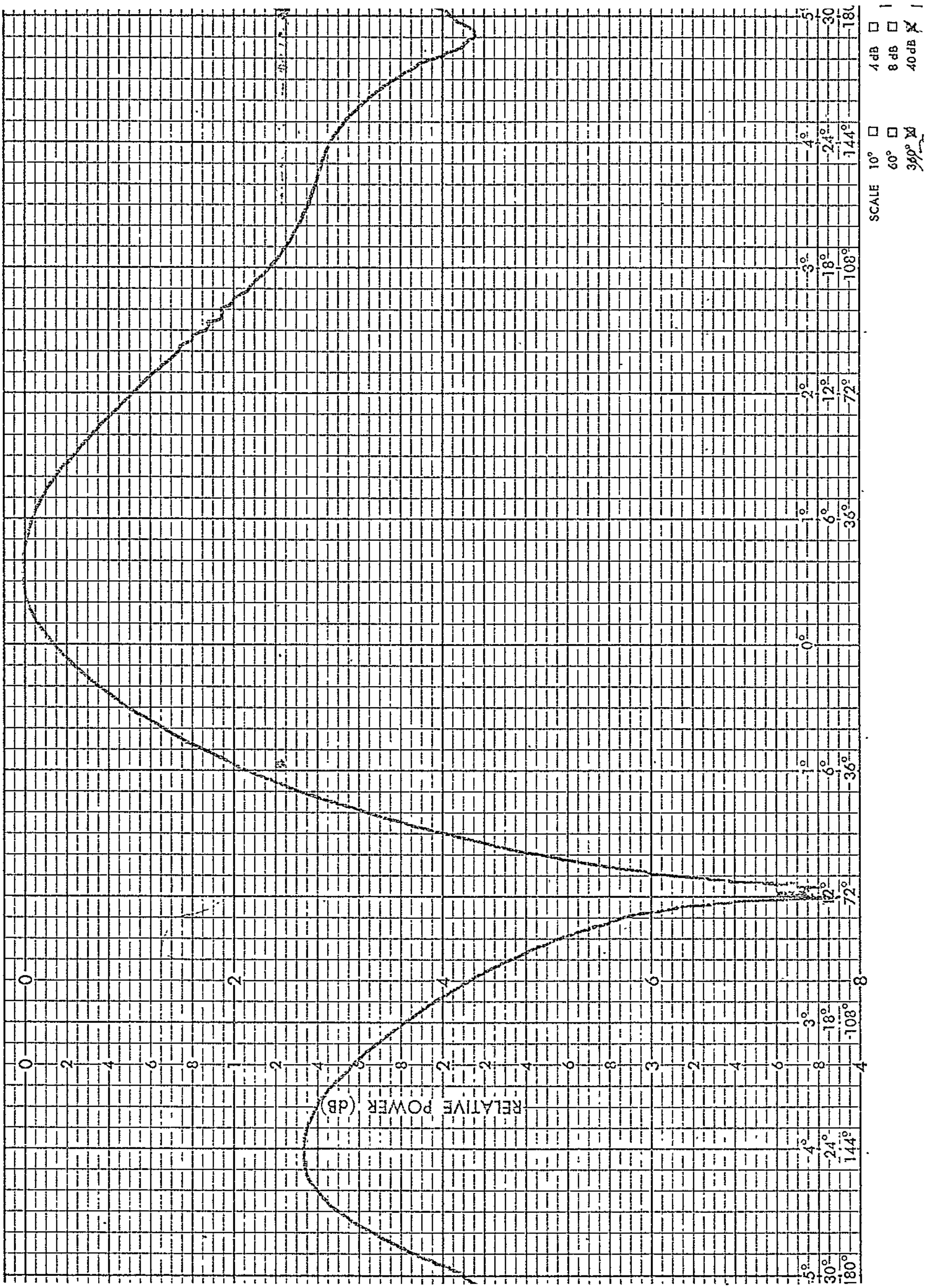


Figure 20. Pattern For Fin With Foam and Teflon Dielectric In Transmission Line, Rotating Polarization

line length, and pattern measurements were repeated. These patterns are shown in Figures 15 through 20. These patterns are grouped into three sets of two each with each set corresponding to an antenna with successively more foam replaced with teflon. The results show that changing the electrical length of the transmission line does indeed change the axial ratio and circularly polarized pattern. But for all these cases the gain was quite low and unacceptable.

The use of the folded transmission line along side the fin actually creates a combination fin and slot in a plane parallel to the antenna groundplane at a level 1.23 inches above the surface. This slot and fin could produce circular polarization if they could be fed 90° cout of phase and the energy from the other side of the slot could be blocked. Four different configurations for blocking energy on the other side of the fin were tried. These are sketched in the cross sectional views of Figure 21. Figure 21a shows one side of the antenna completely blocked. The pattern for this case is shown in Figure 22. The pattern for the slightly opened configuration of Figure 21b is shown in Figure 23. The patterns for the simple shorting plates at 1/2" and 3/4" spacings shown in Figures 21c and 21d are shown in Figures 24 and 25 respectively.

None of these attempts to produce good circularity near the zenith were successful. It was finally concluded that the metallic structures in the vicinity of the fin were sufficient to disturb

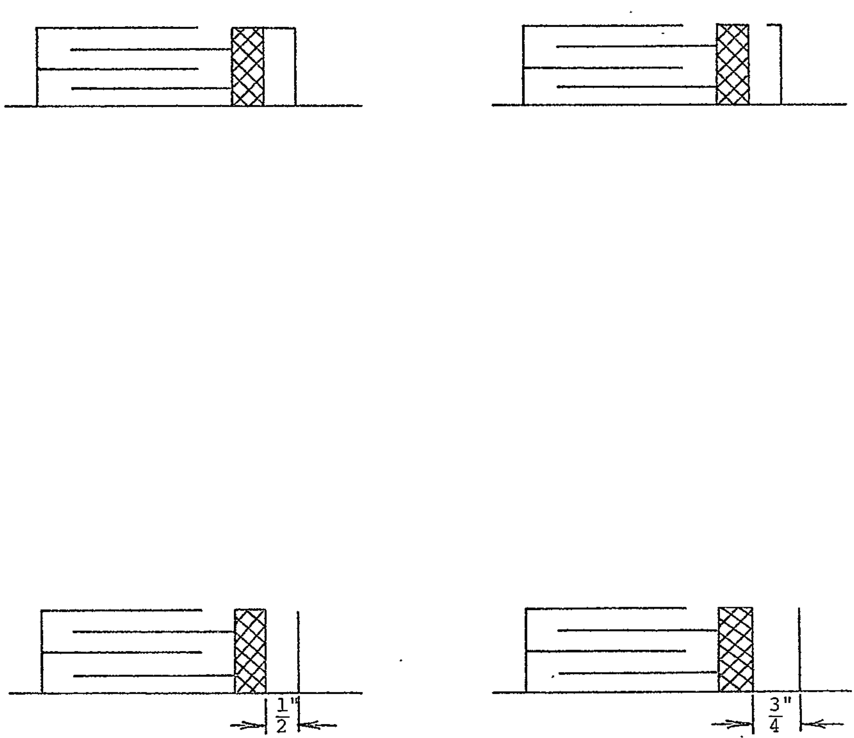


Figure 21. Cross-Sections of Configurations For Blocking One Side of Slot

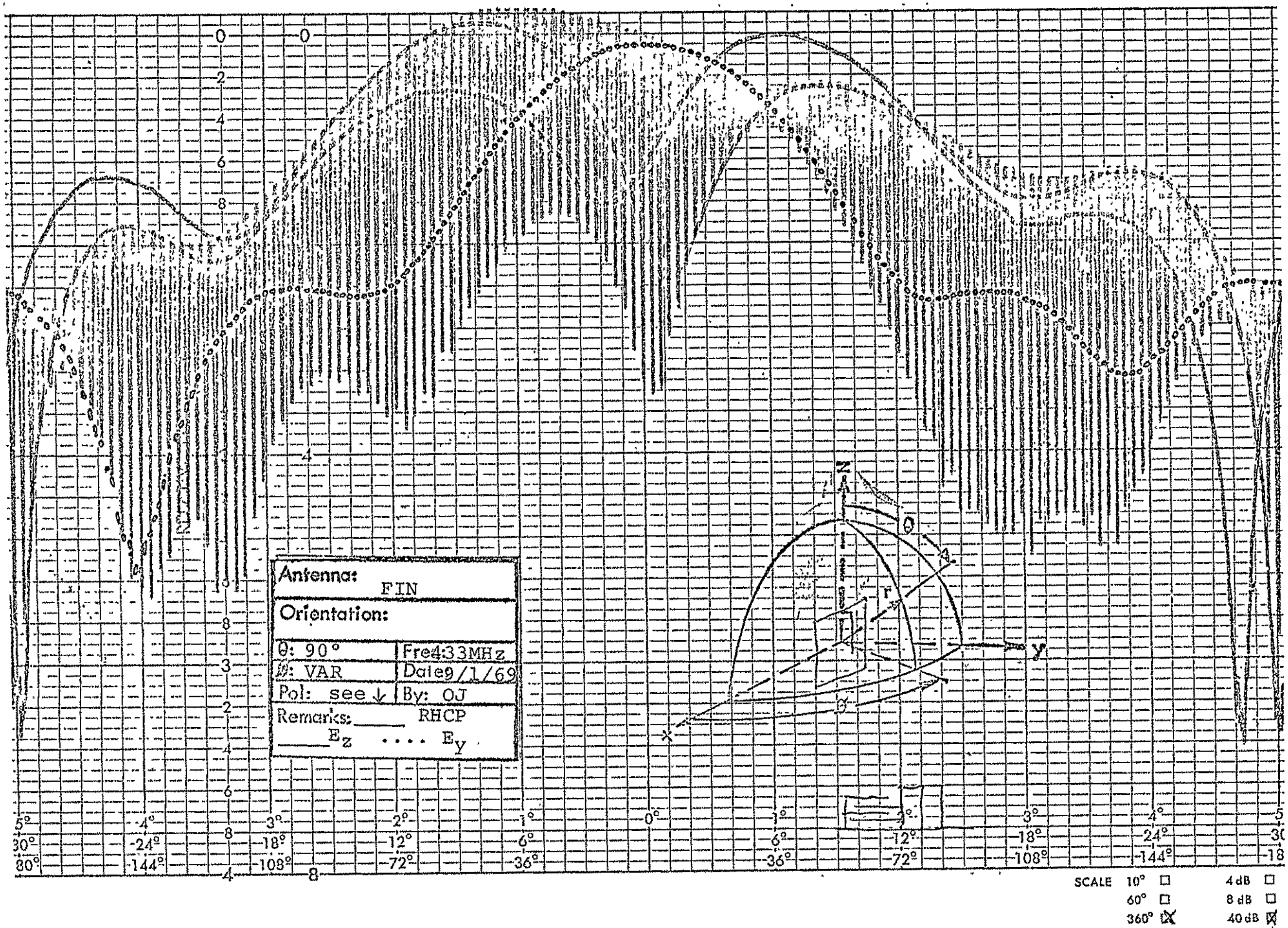


Figure 22. Pattern For One Side Completely Blocked

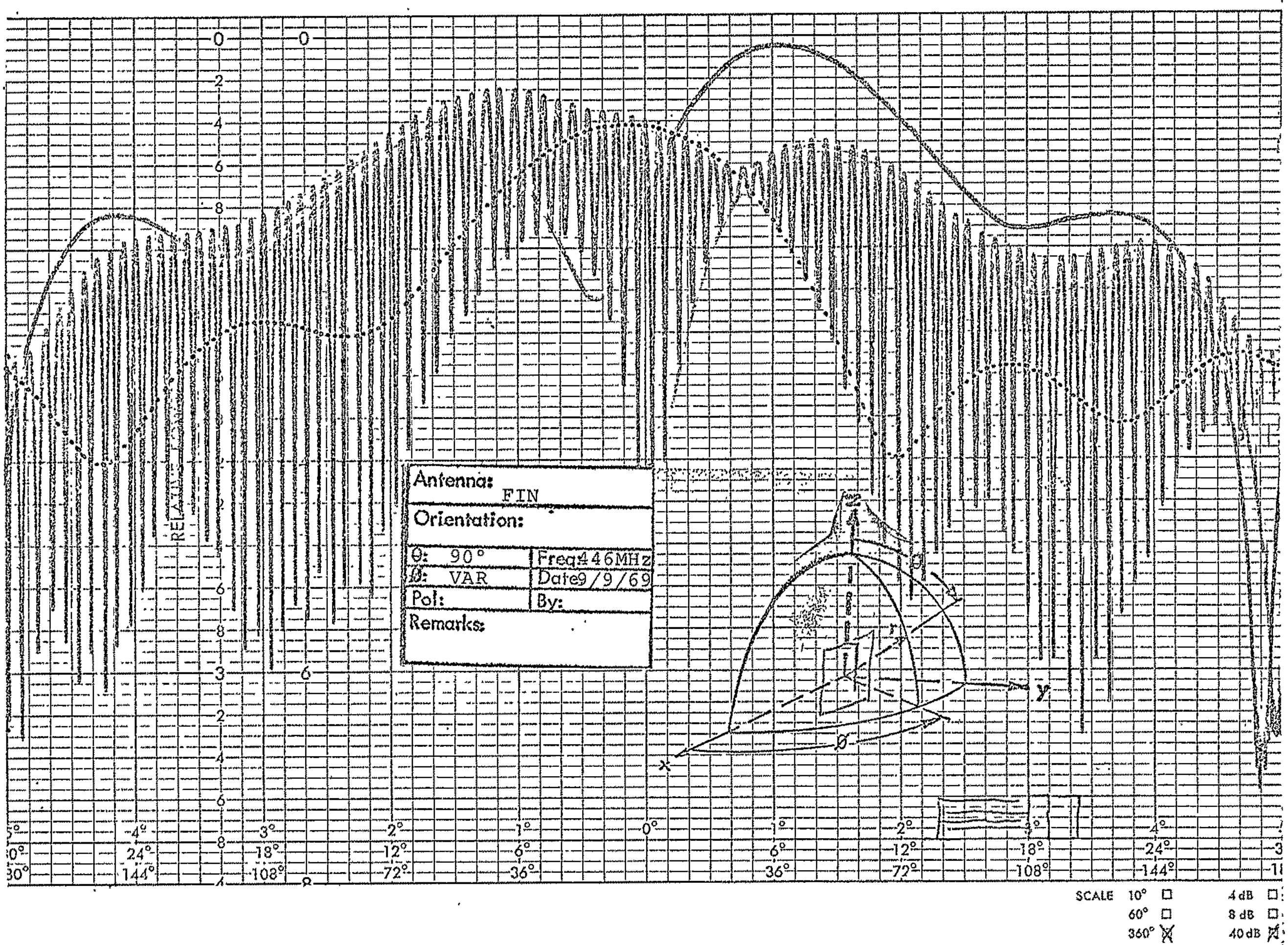


Figure 23. Pattern For Blocking Cavity Opened.

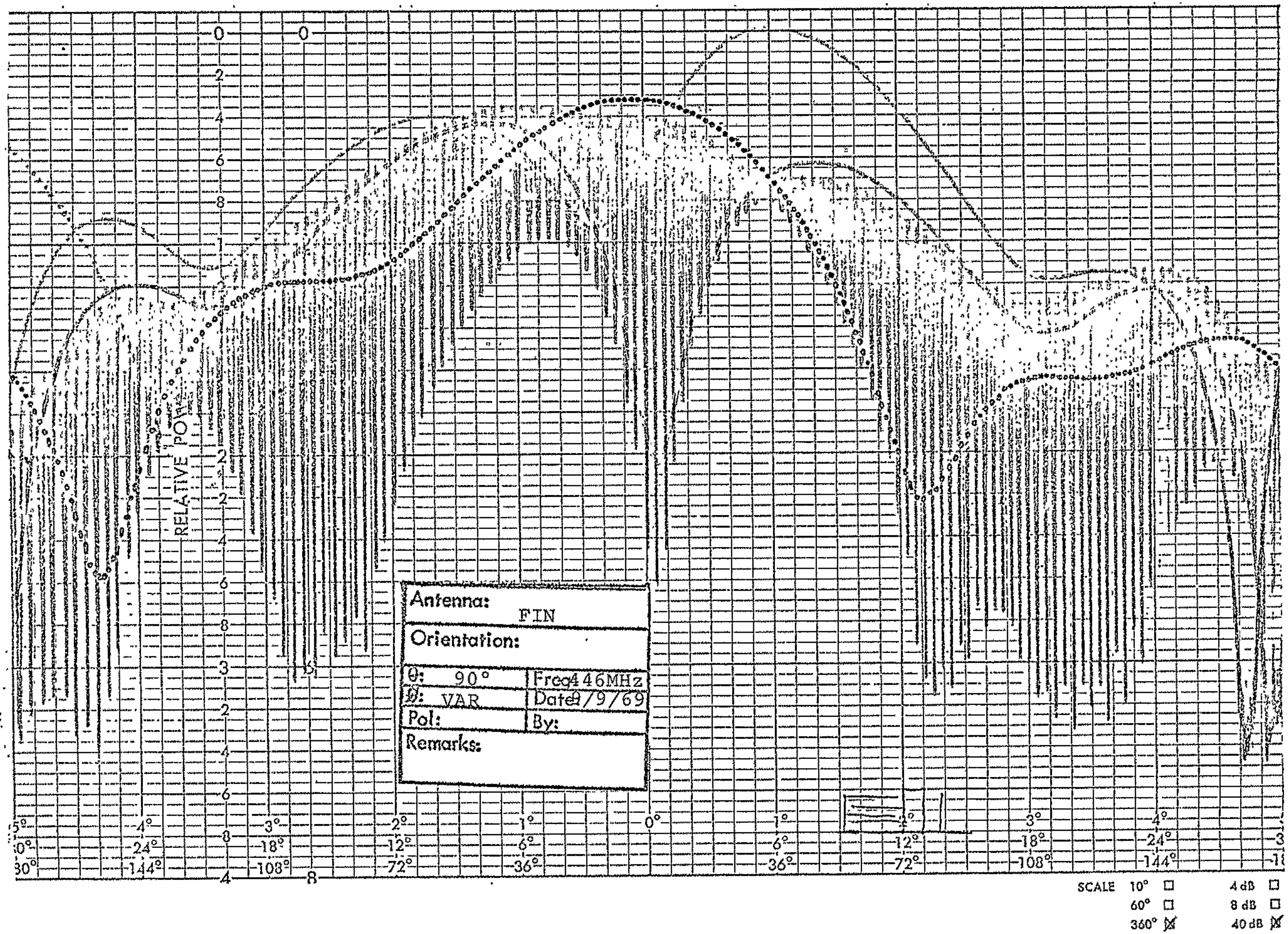


Figure 24. Pattern For Blocking Plate 1/2" From Fin

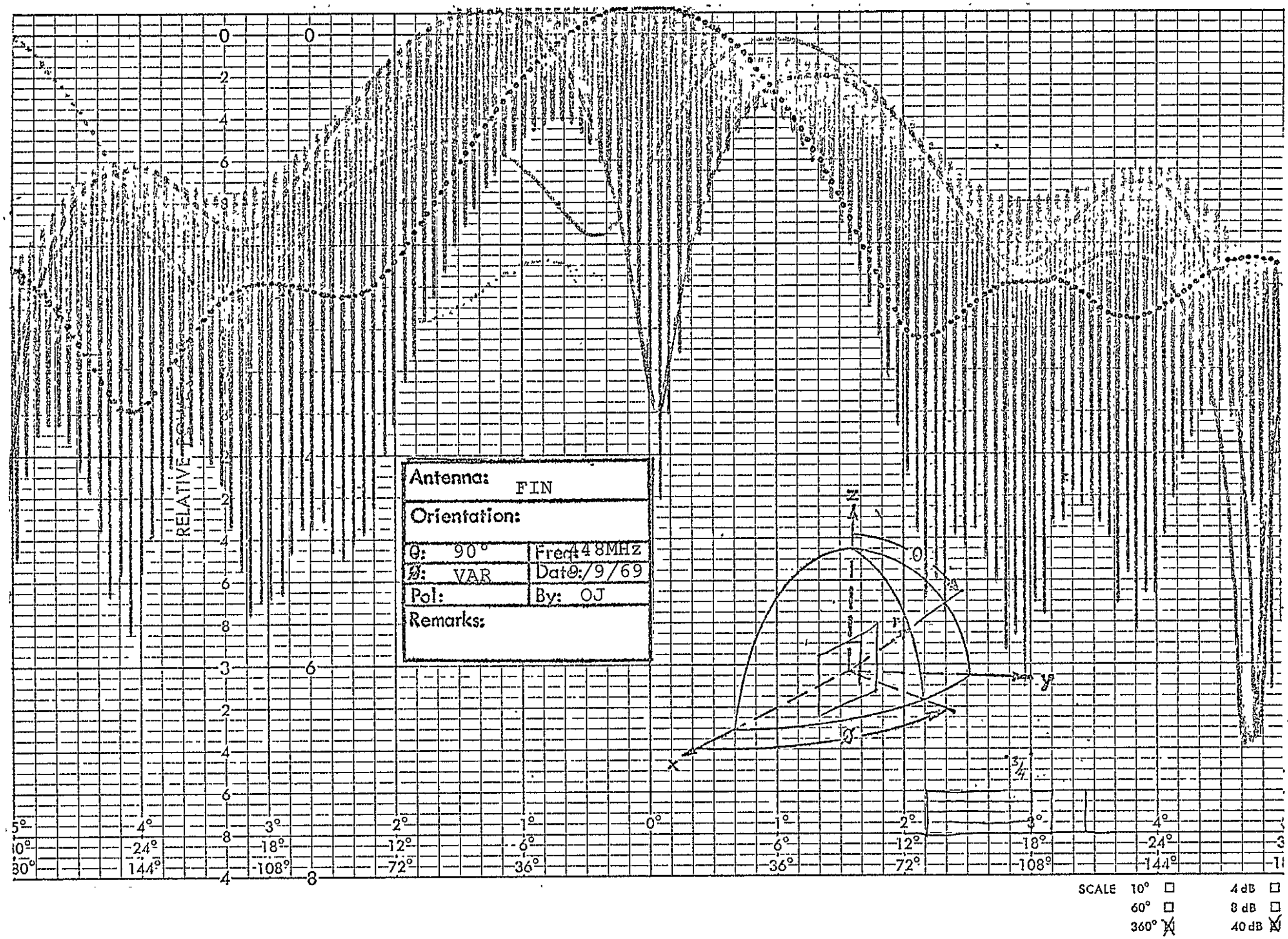


Figure 25. Pattern For Blocking Plate 3/4" From Fin

the fin feeding and produce high circulating currents that effectively reduced the gain below an acceptable level. With this approach abandoned it was then decided to attempt to improve the circularity by placing a slot in the groundplane beneath the fin.

2.3 Fin On Slotted Groundplane

A number of slot configurations were tried in an attempt to improve the fin polarization circularity near zenith. The first was a slot one-half wavelength long inclined at an angle of 45° to the fin and centered beneath the fin. Patterns for this configuration are shown in Figures 26 and 27. These patterns are for operating frequencies of 385 MHz and 420 MHz respectively. These patterns indicate that the 45° slot does not produce satisfactory results. Before abadoning the groundplane concept entirelly, another slot was made inclined at an angle of 22 1/2° to the fin and centered beneath the fin. The pattern for this arrangement is shown in Figure 28.

The patterns of Figures 26 through 28 show that the slotted groundplane does not materially improve the antenna performance.

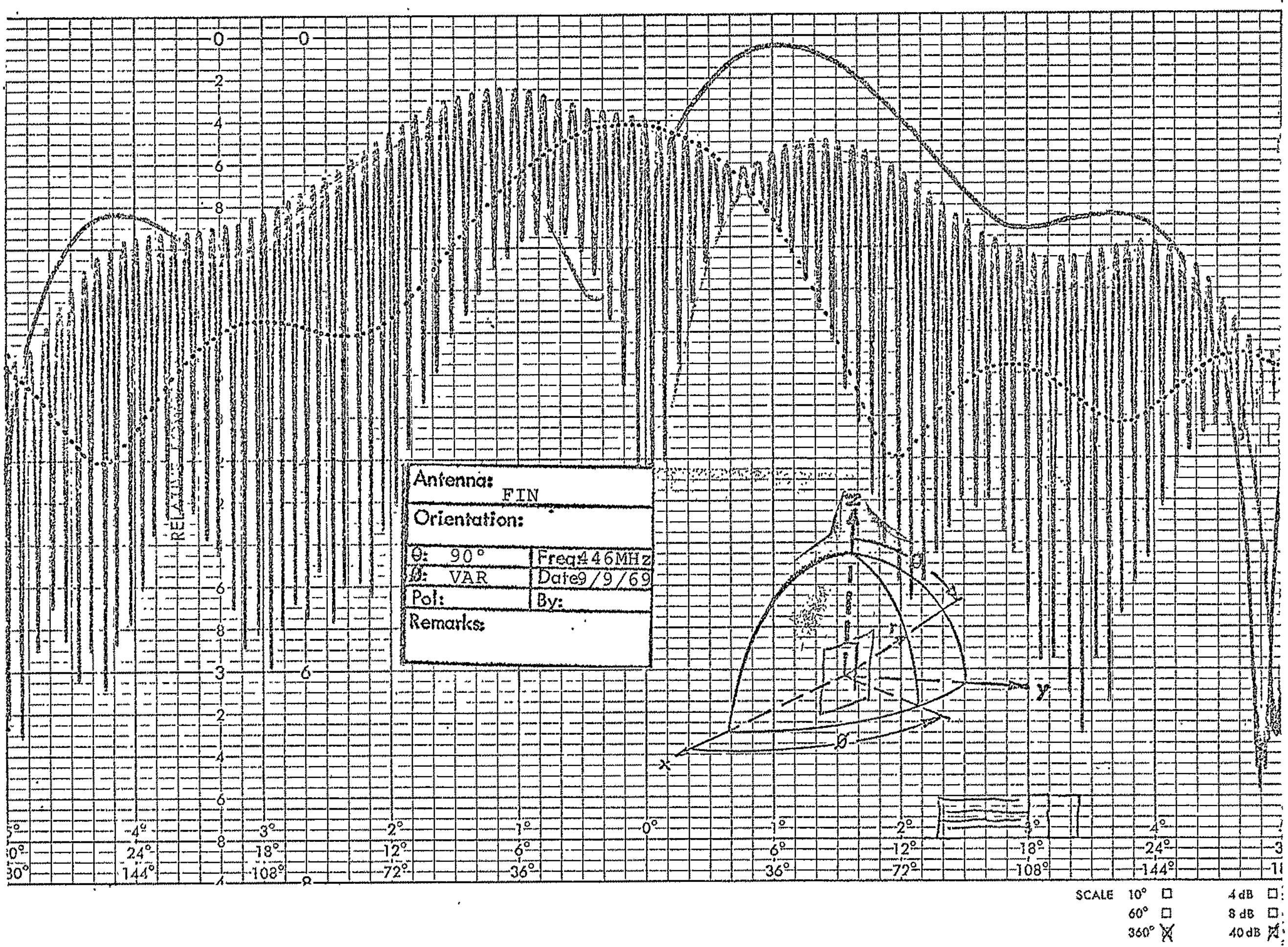


Figure 23. Pattern For Blocking Cavity Opened.

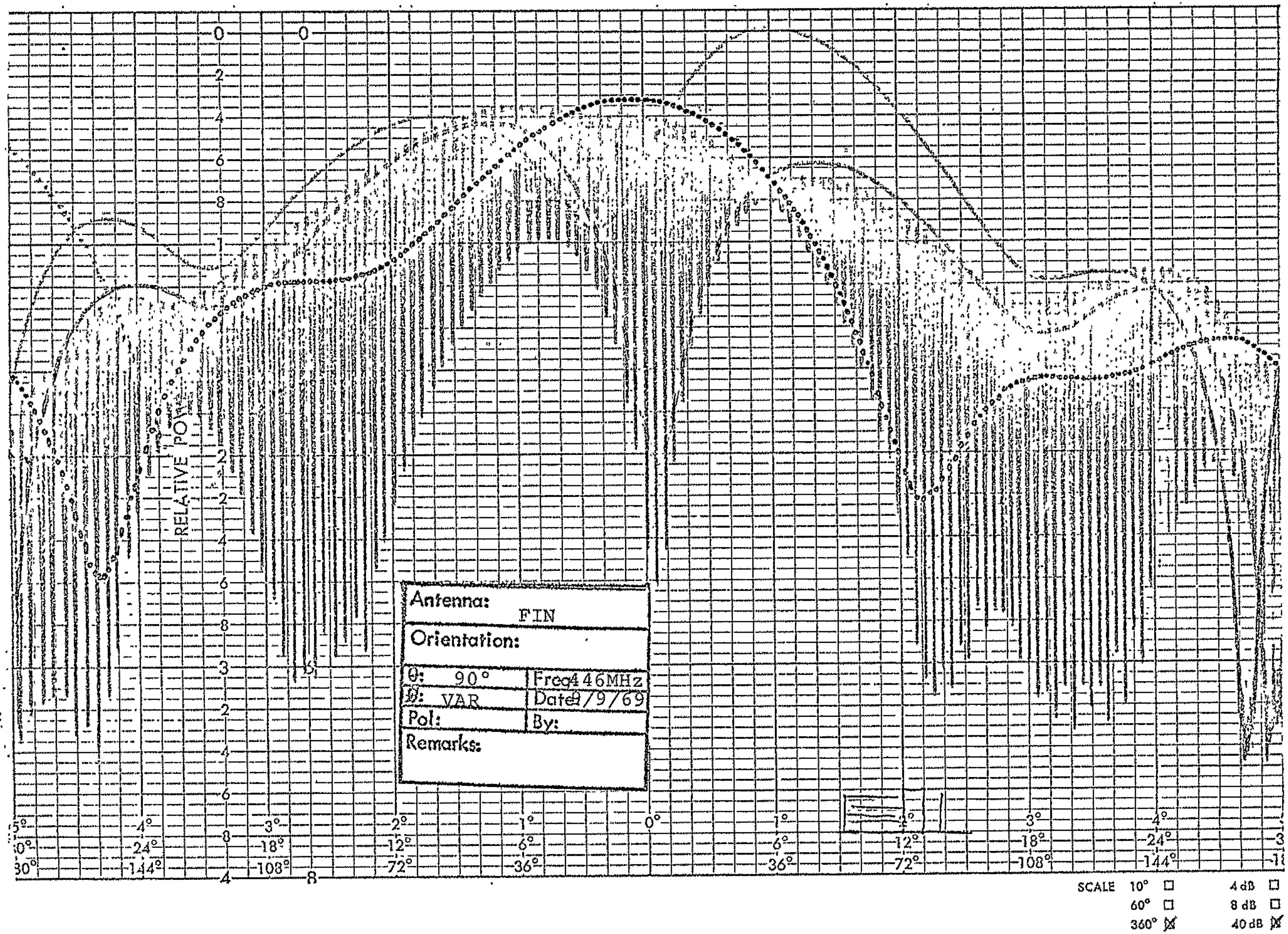


Figure 24. Pattern For Blocking Plate 1/2" From Fin

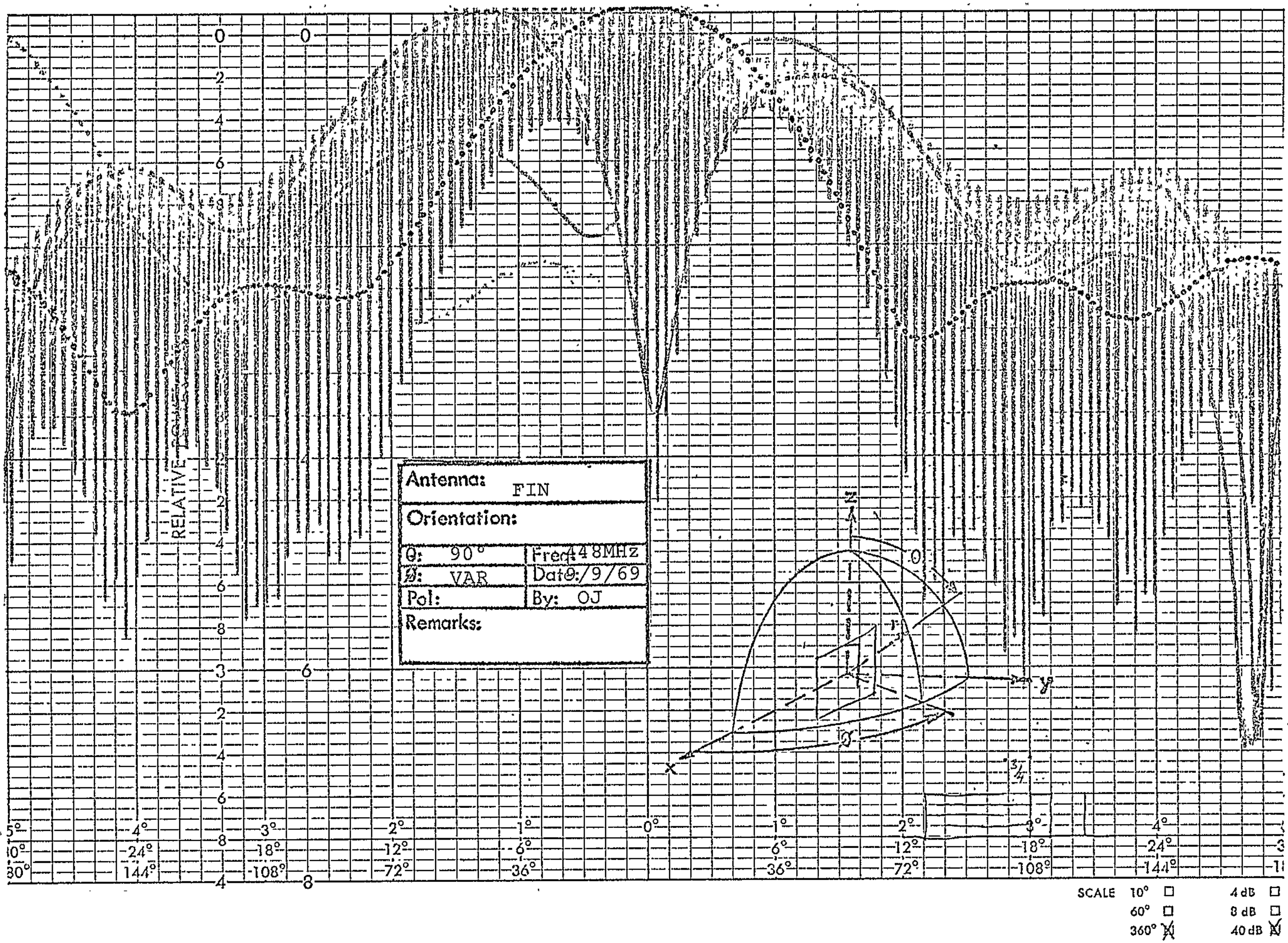


Figure 25. Pattern For Blocking Plate 3/4" From Fin

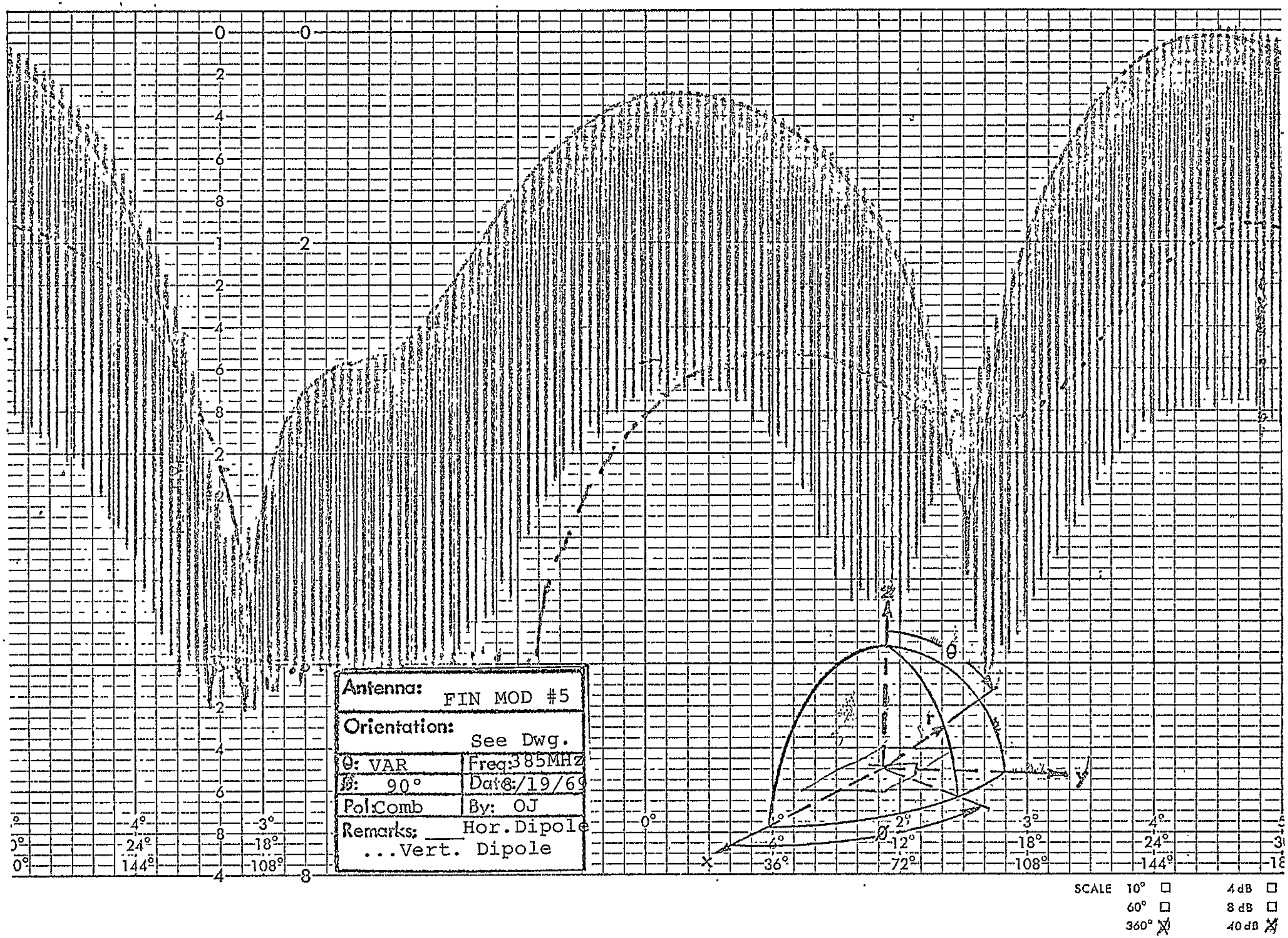


Figure 26. Pattern For Fin With 45° Slot 385 MHz

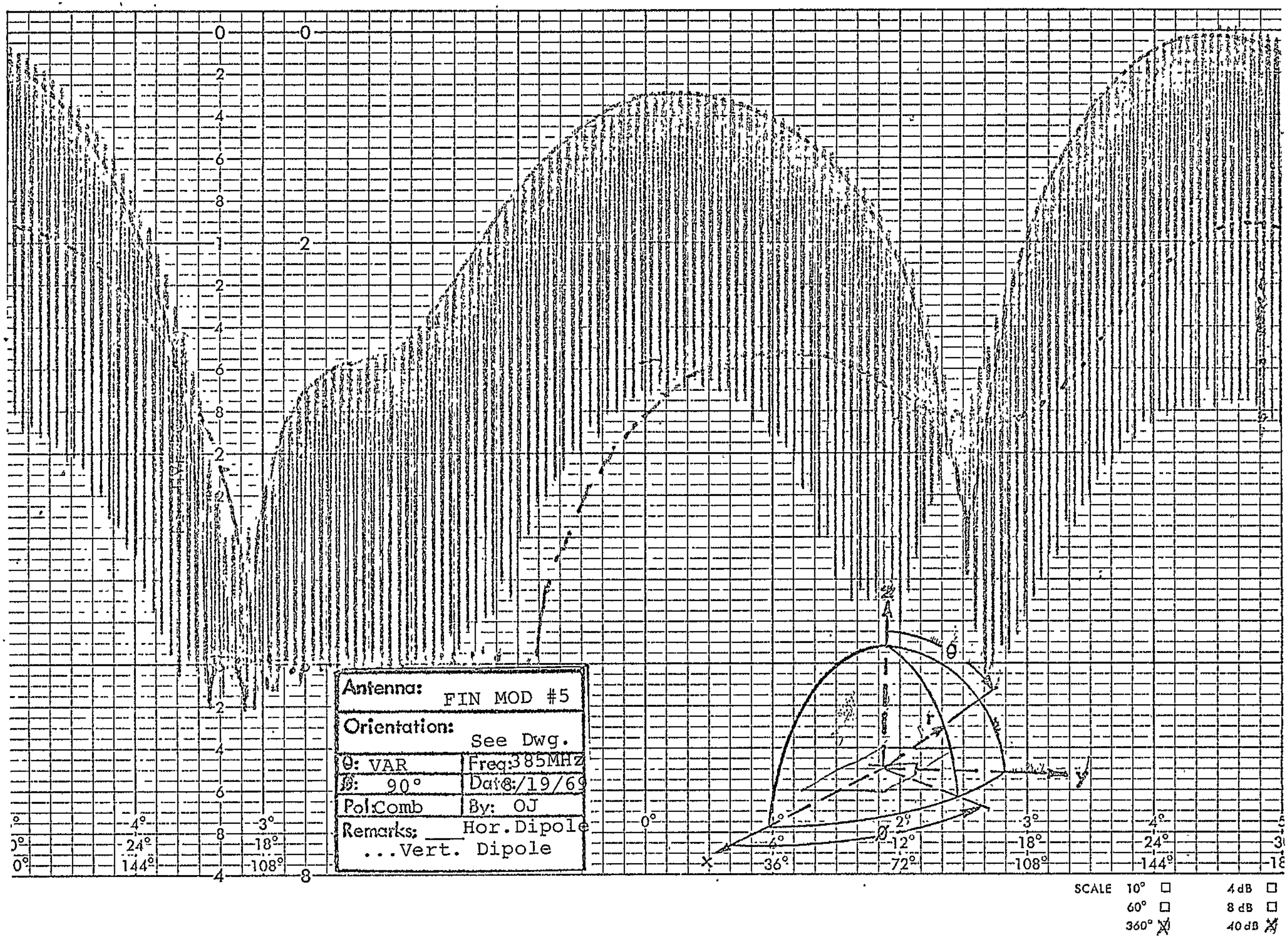


Figure 26. Pattern For Fin With 45° Slot 385 MHz

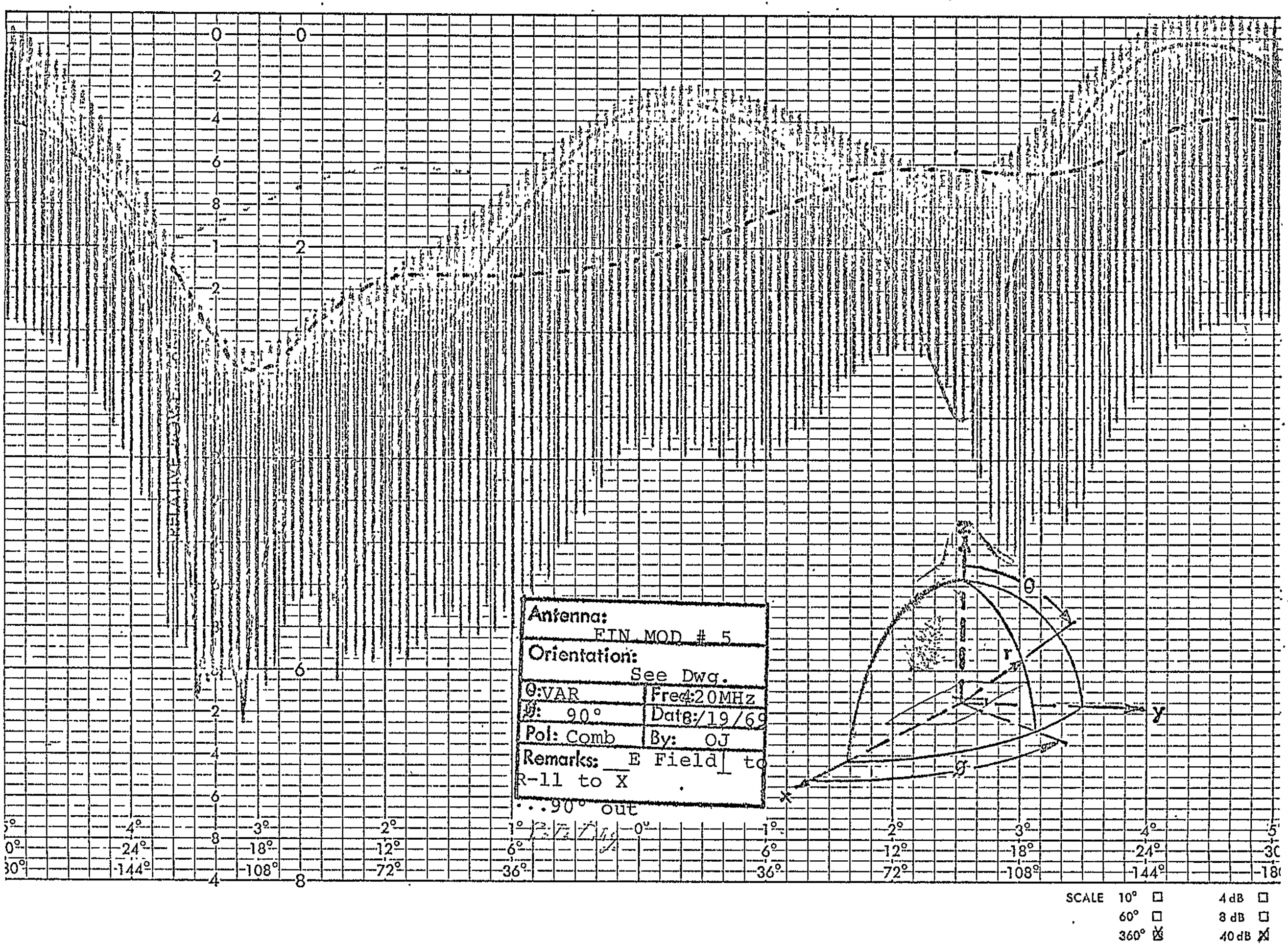


Figure 27. Pattern For Fin With 45° Slot 420 MHz

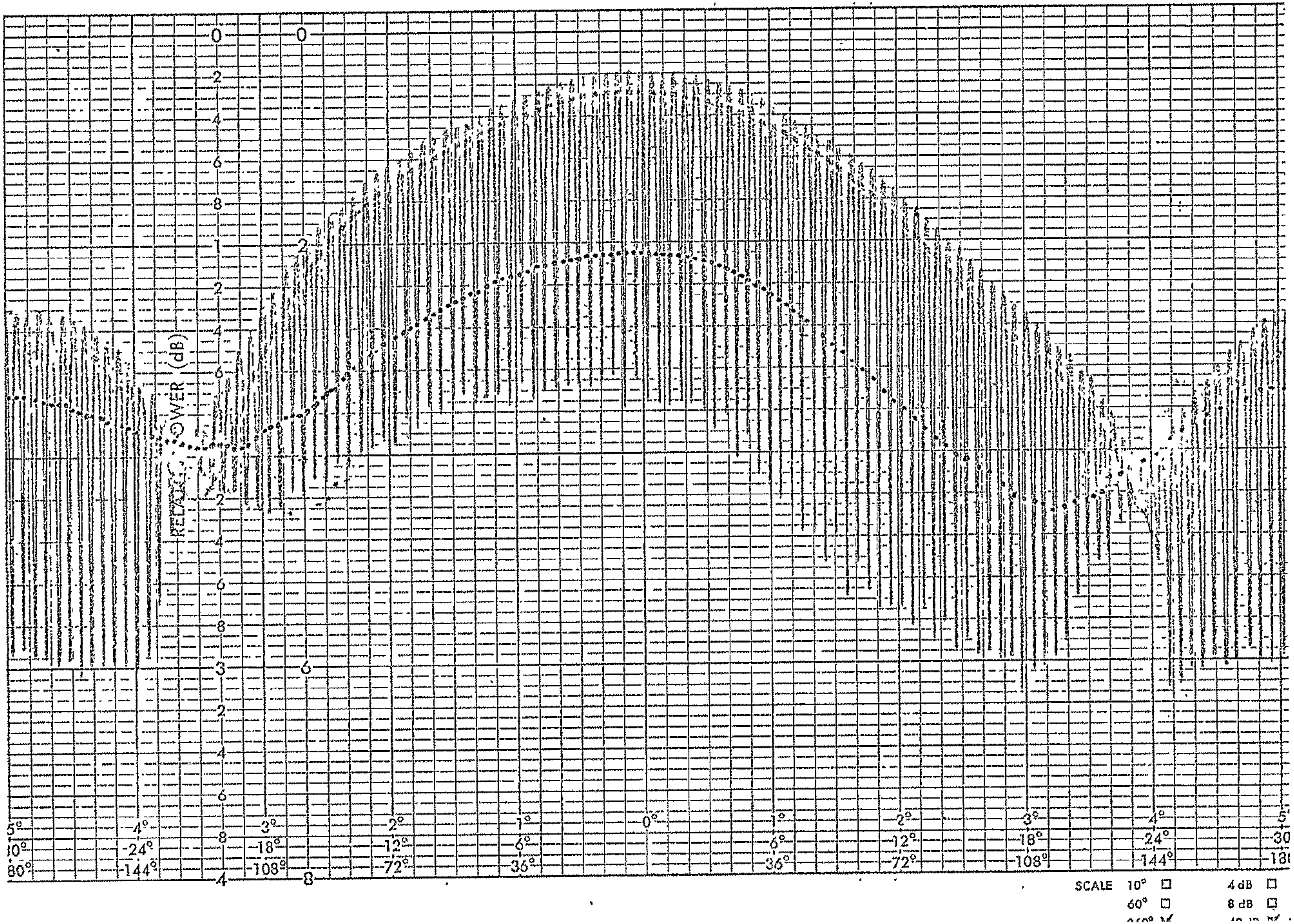


Figure 28. Pattern For Fin With 22.5° Slot

2.4 FIN WITH PARASITIC FIN

The work described in Sections 2.1 through 2.3 above lead to the conclusion that a single fin would not be satisfactory, and a study was made of double fin configurations. This study begin with an examination of the patterns obtainable from a single fin mounted at the edge of a groundplane. These patterns are shown in Figures 29 and 30. The patterns of Figures 29 and 30 are quite similar to the patterns of Figures 3 and 5 with some deterioration due to moving the fin off center. A parasitic fin was then placed on the groundplane at a distance of one quarter wavelength. The patterns for this configuration are shown in Figures 31 and 32. Note that this configuration produces a circular polarization pattern with a null 18db. below the peak occuring approximately 18° from zenith, a pattern which is unacceptable. The same configuration was then repeated with a parasite spaced at 1/8 wavelength. The patterns for this case are shown in Figures 33 and 34. For this case the null is only 13db. below the peak, but it is still unacceptably deep. Next the parasite fin was rotated 180° about an axis through the center perpendicular to the groundplane. Patterns for this configuration with quarter wavelength spaced fins are shown in Figures 34 and 35. Patterns for 1/8 wavelength spaced fins are shown in Figures 36 and 37. Note that these configurations have relatively symmetrical circular polarization patterns (as shown in Figures 35 and 37) with very very poor axial ratio (as shown in Figures 34 and 36). In other words, the good circular pattern is obtained primarly from the symmetrical linear polarization that corresponds to the

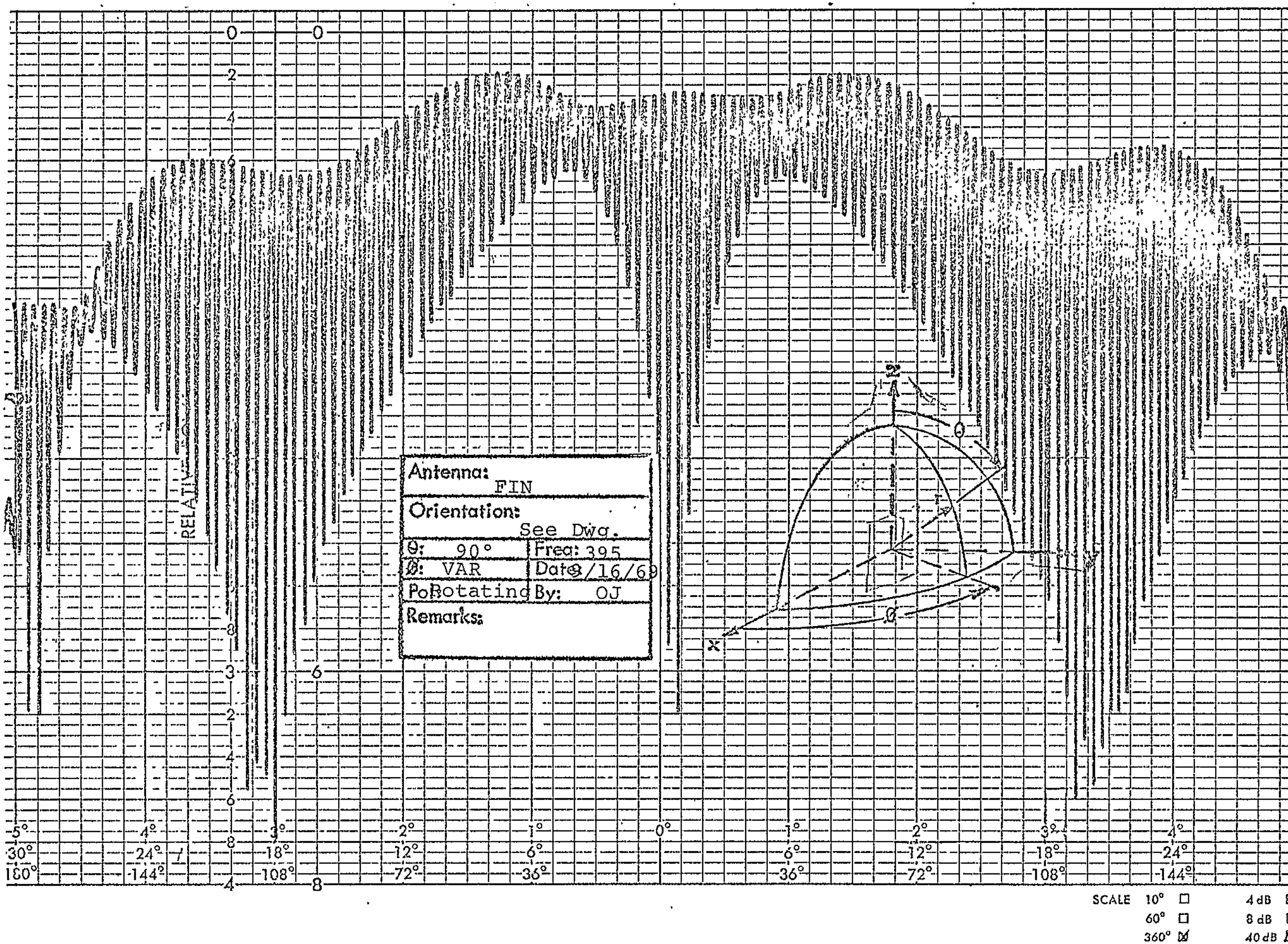


Figure 29. Pattern Of Fin At Edge Of Groundplane Rotating Polarization

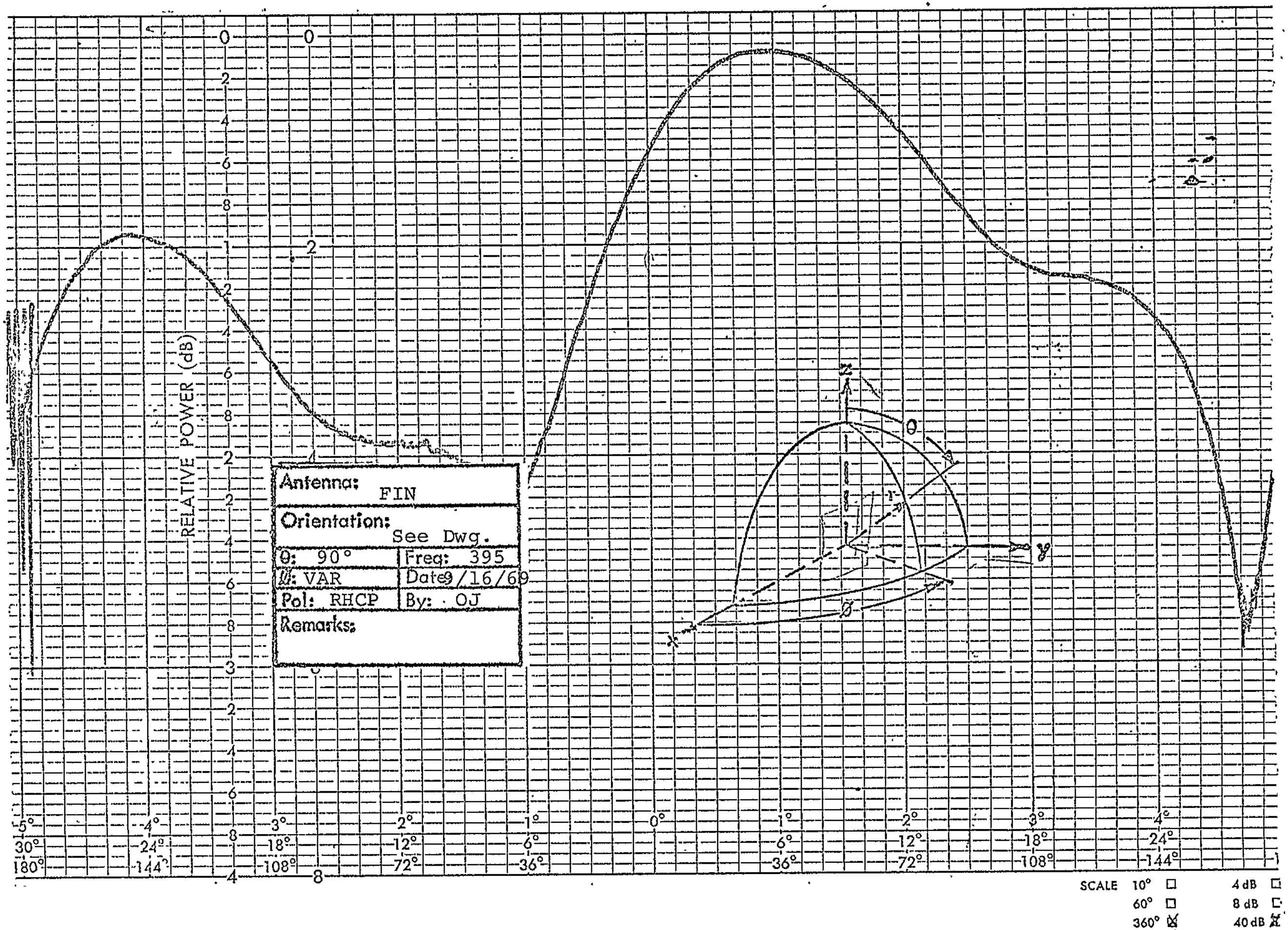


Figure 30. Pattern Of Fin At Edge Of Groundplane
Circular Polarization

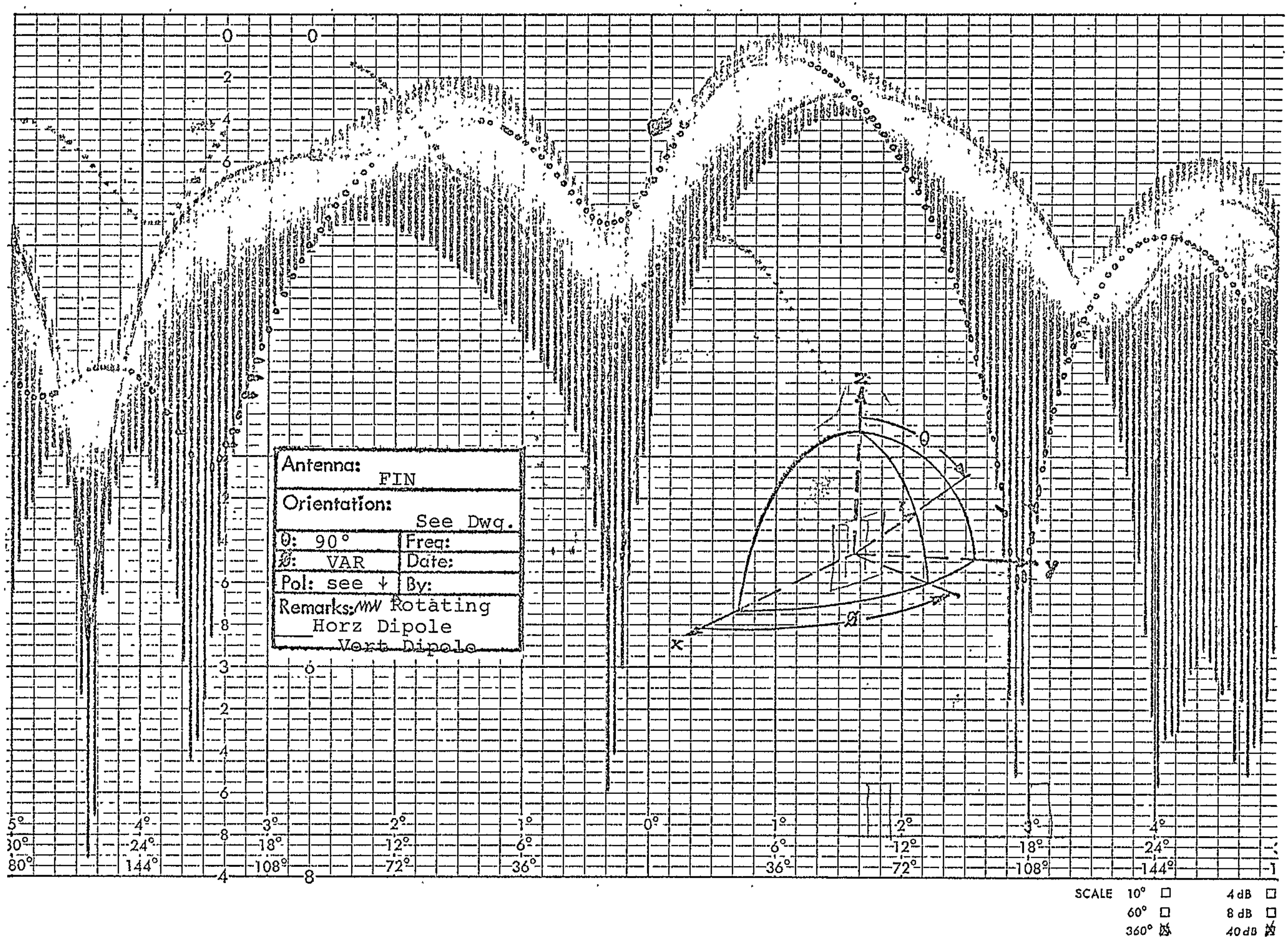


Figure 31. Pattern Of Fin With Parasitic Fin λ/4 Distant, Rotating Polarization

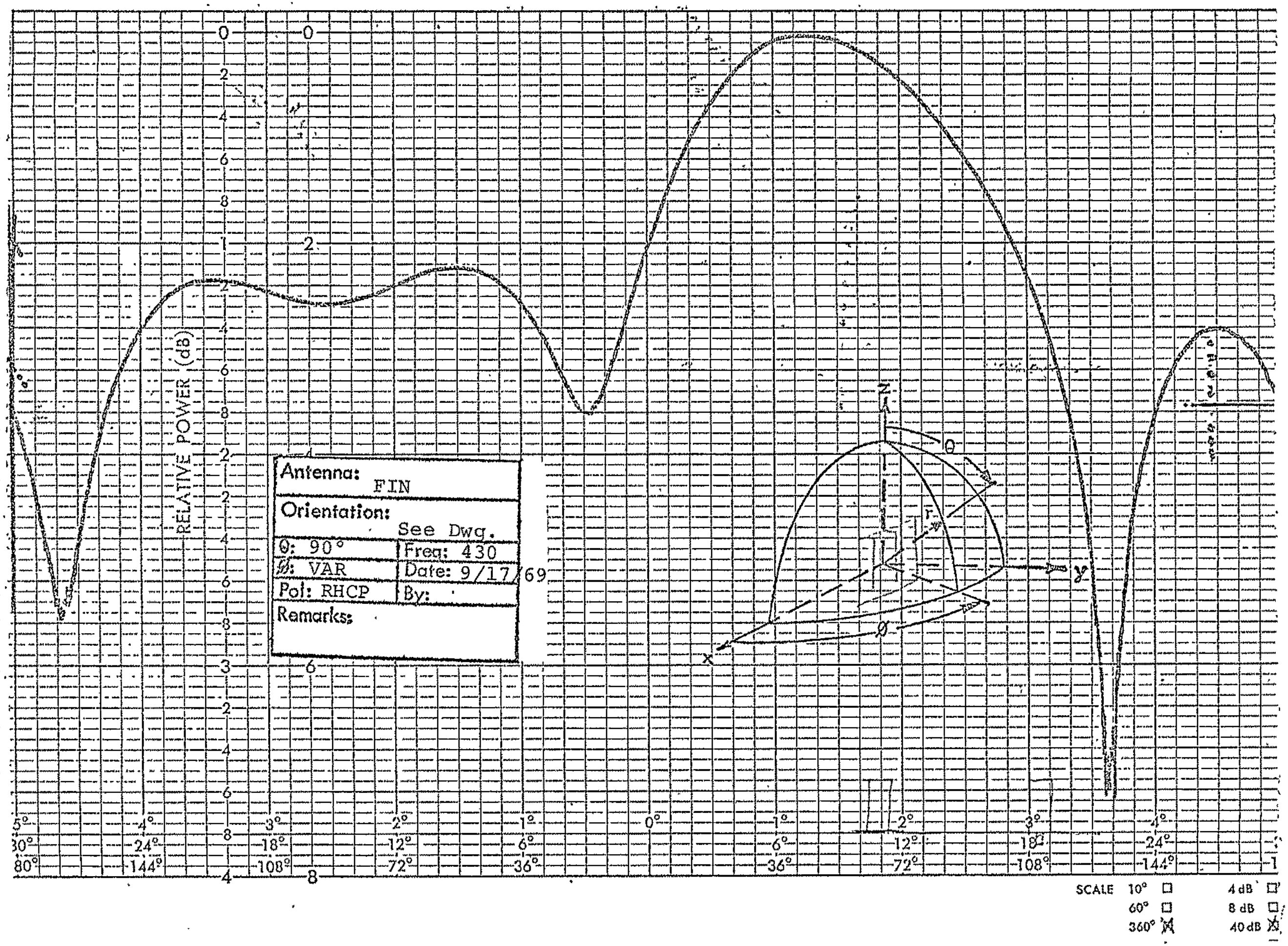


Figure 32. Pattern Of Fin With Parasitic Fin $\lambda/4$ Distant, Circular Polarization

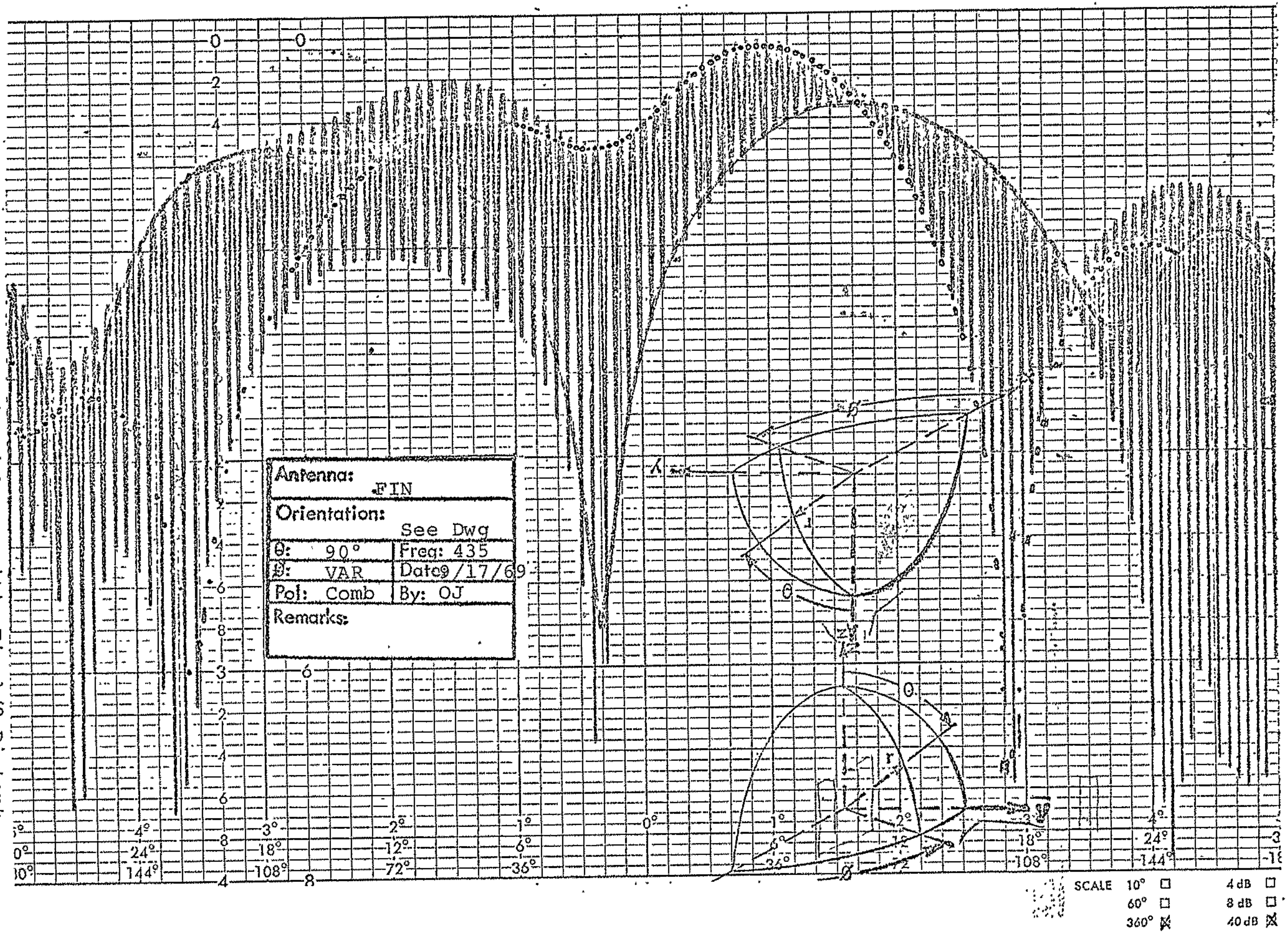


Figure 33. Pattern Of Fin With Parasitic Fin λ/8 Distant
Rotating Polarization

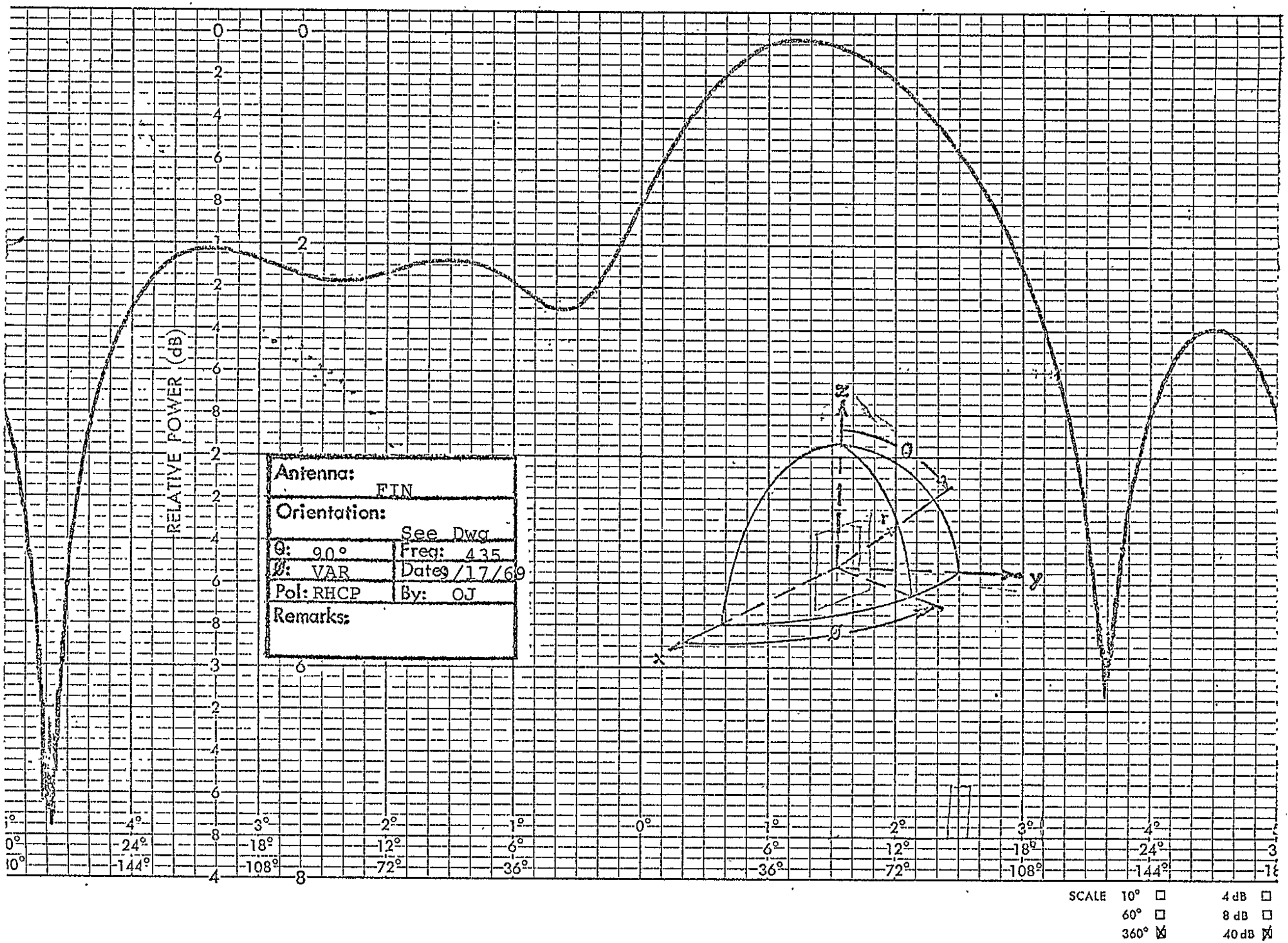


Figure 34. Pattern Of Fin With Parasitic Fin λ/8 Distant Circular Polarization

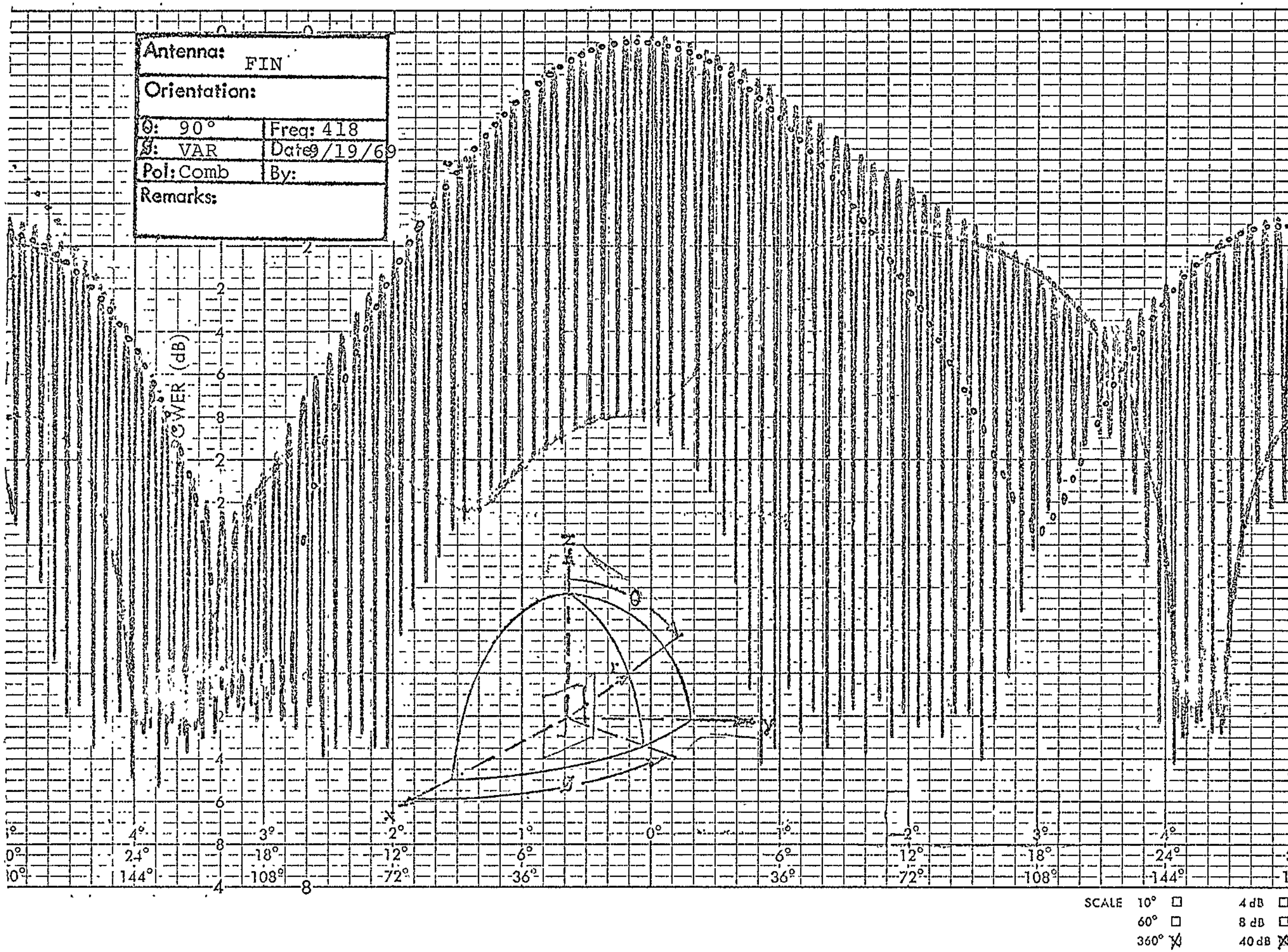


Figure 35. Pattern of Fin With Reversed Parasite λ/4 Distant, Rotating Polarization

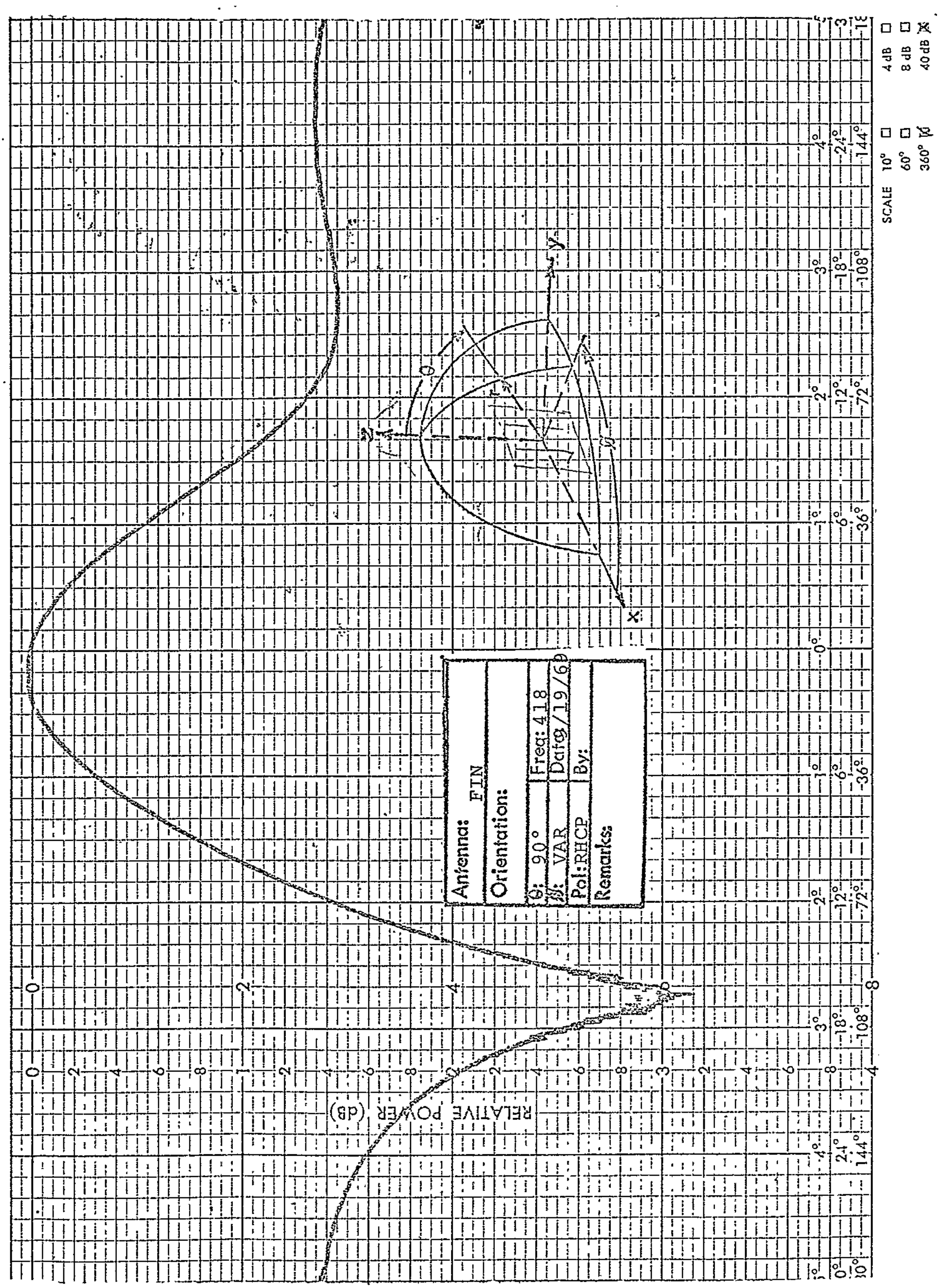
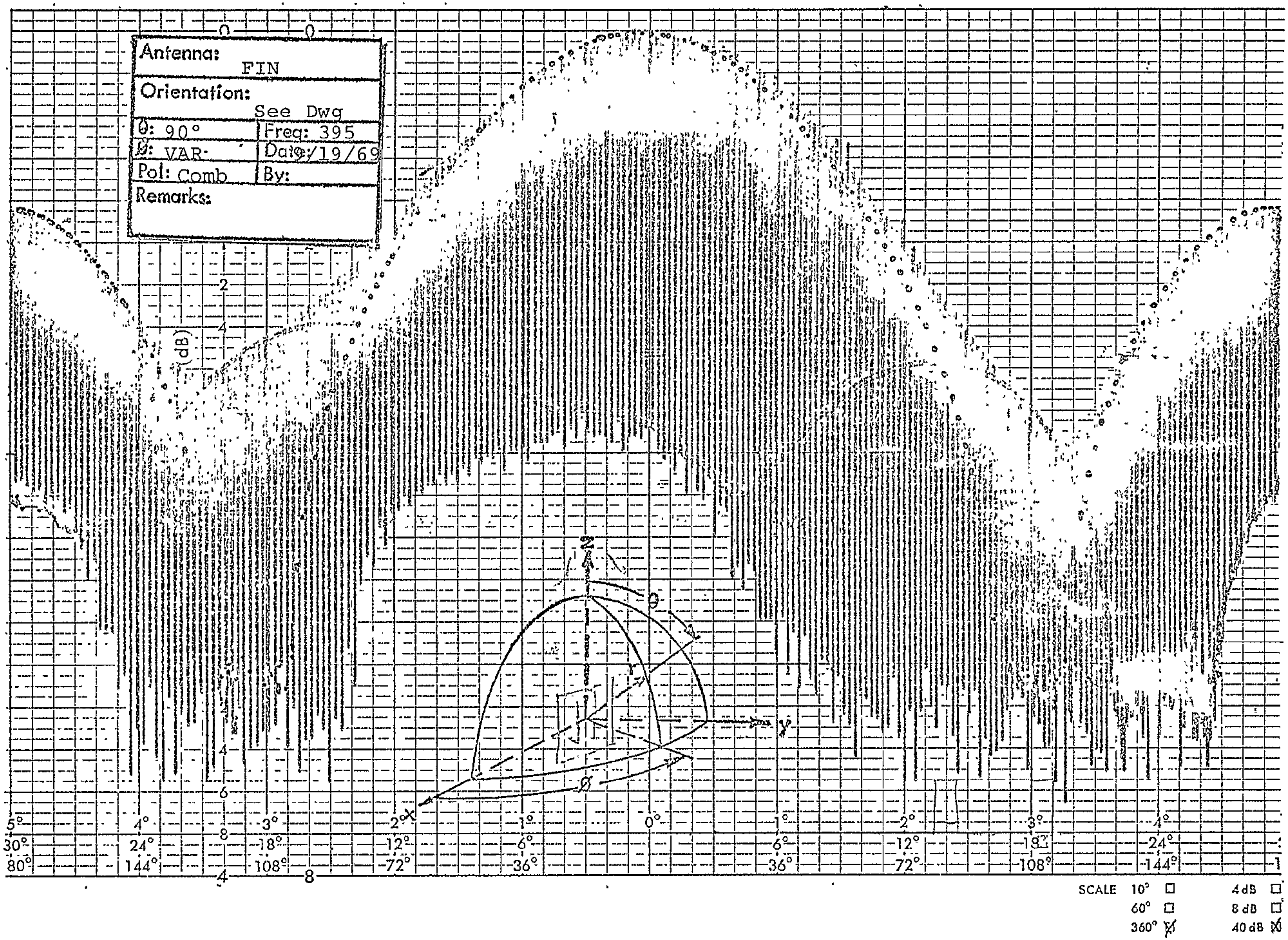


Figure 36. Pattern of Fin With Reversed Parasite $\lambda/4$ Distant, Circular Polarization

Figure 37. Pattern Of Fin With Reversed Parasite $\lambda/8$ Distant, Rotating Polarization



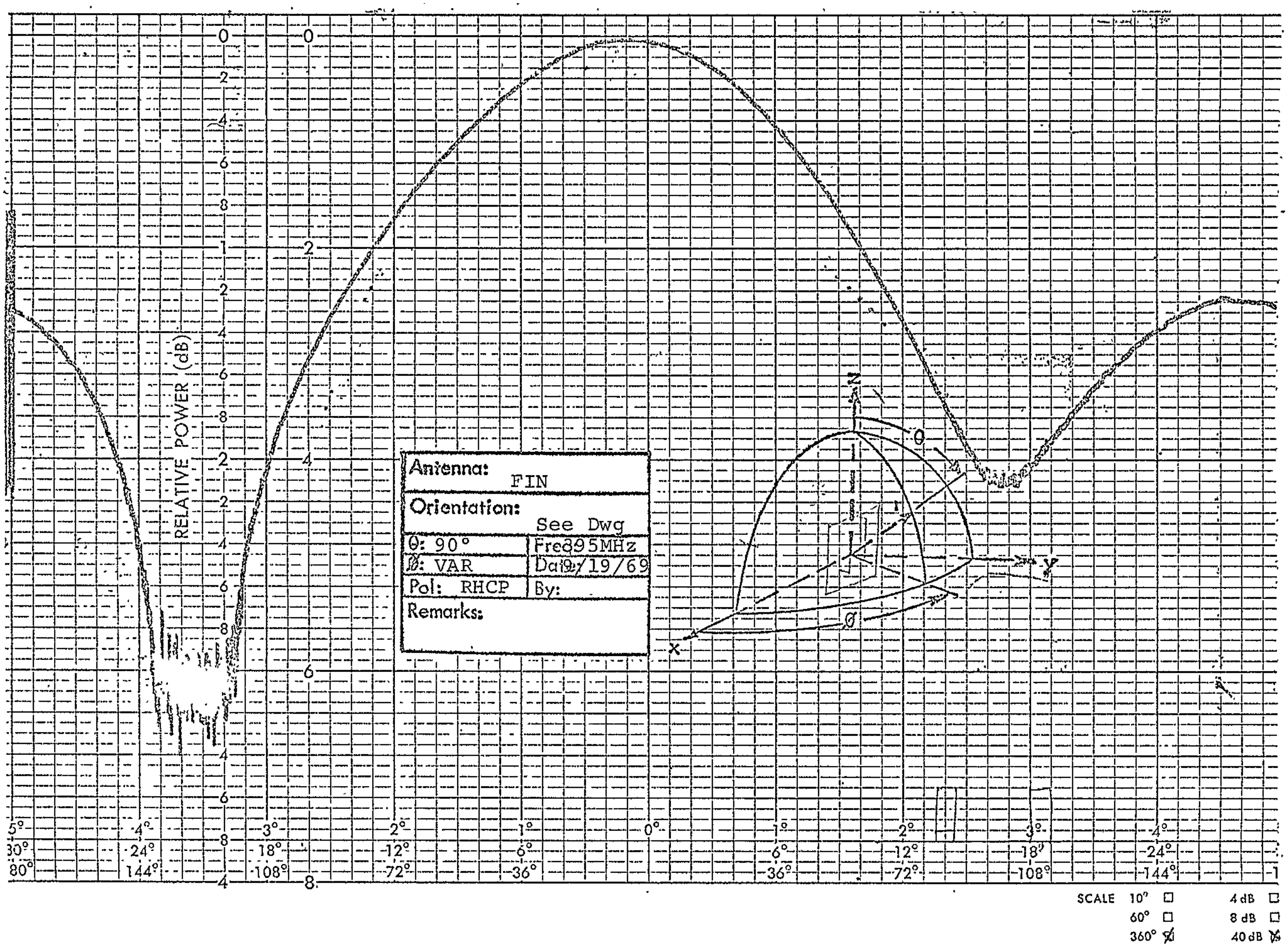


Figure 38. Pattern of Fin With Reversed Parasite λ/8 Distant, Circular Polarization

peak of the rotating polarization pattern. The reversal of the fin thus eliminates one of the polarization components and results in an unsatisfactory antenna.

Next an experiment was made to open the top of the active fin so that it appeared as two plates. The patterns for a single fin of this type at the edge of the groundplane are shown in Figures 39 and 40. These patterns again are very similar to the patterns originally obtained in Figures 3 and 5.

The results of placing a parasitic fin at one-quarter wavelength from the open fin are shown in Figures 41 and 42 and similar patterns for the parasite reveresed 180° are shown in Figures 43 and 44.

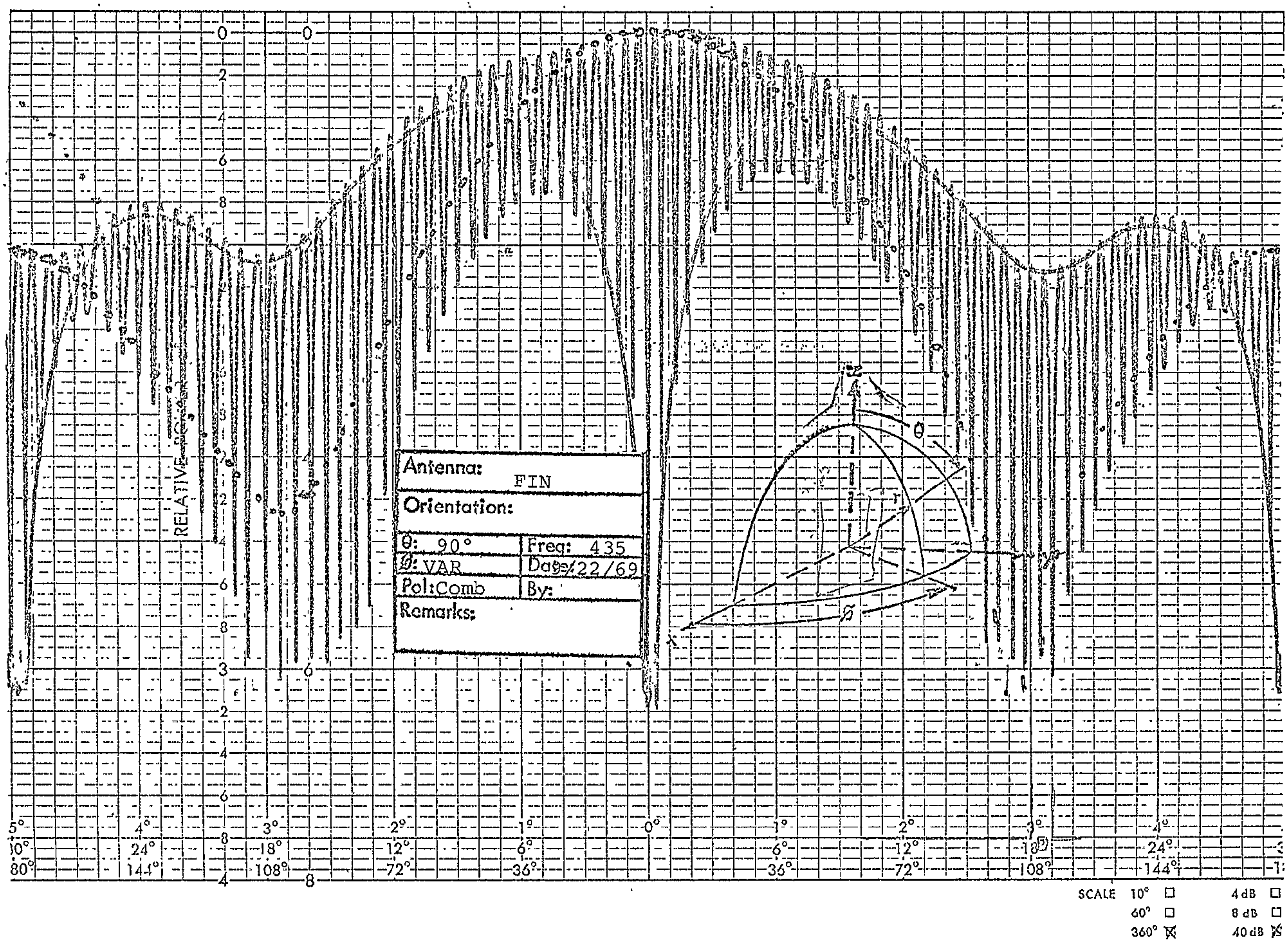


Figure 39. Pattern of Fin With Open Top, Rotating Polarization

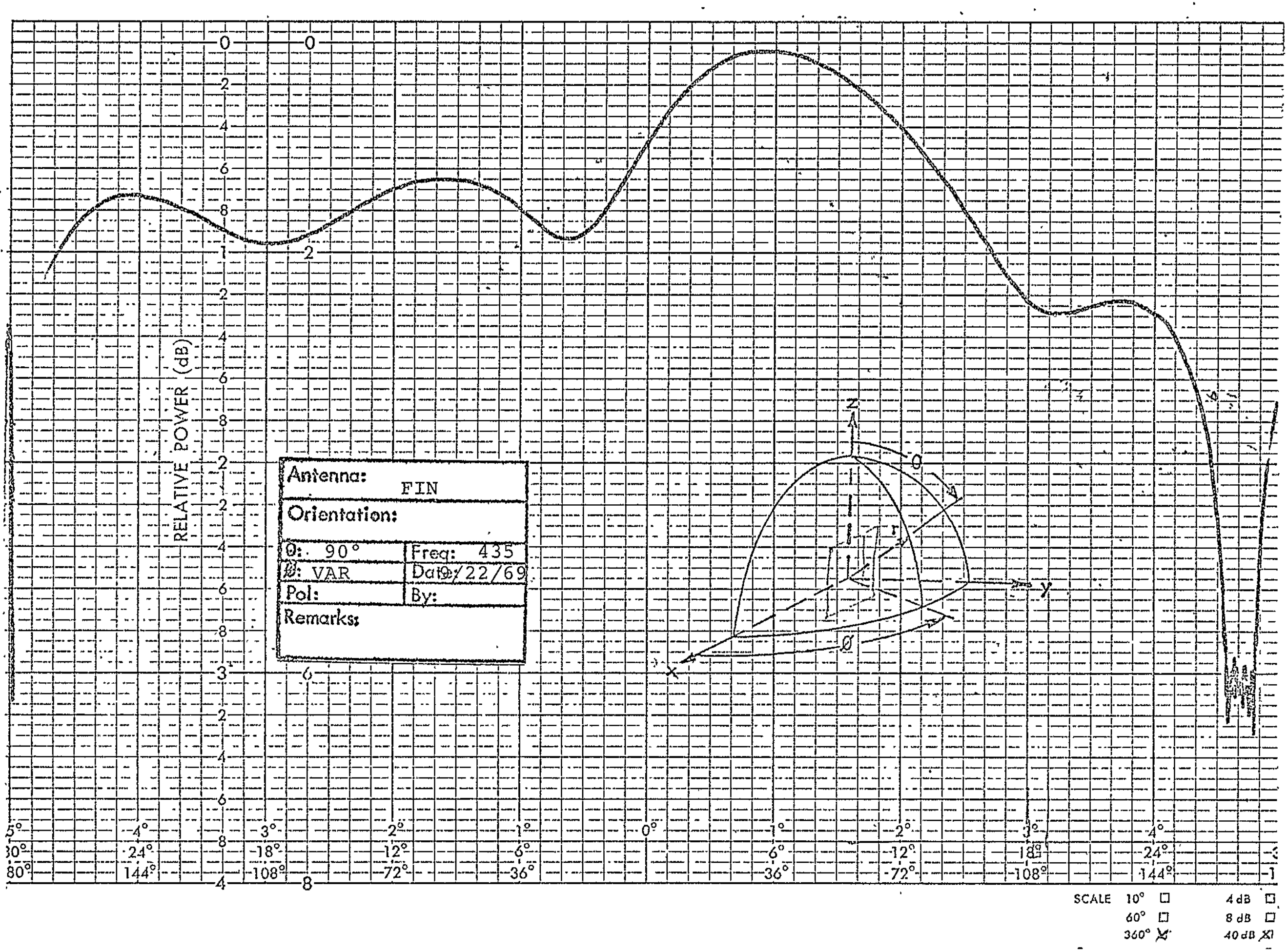


Figure 40. Pattern of Fin With Open Top, Circular Polarization

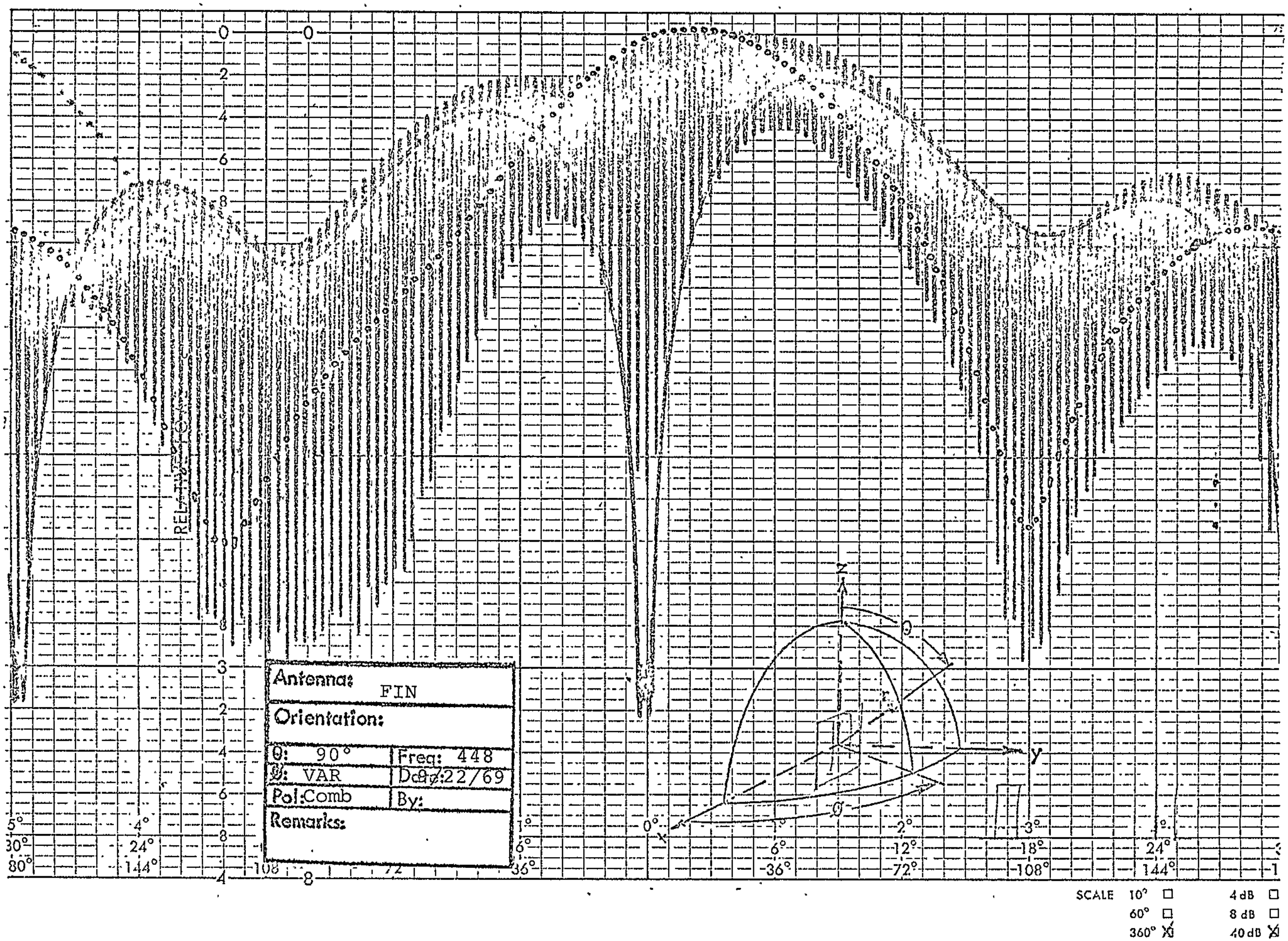


Figure 41. Pattern of Fin With Open Top, λ/4 From Parasite, Circular Polarization

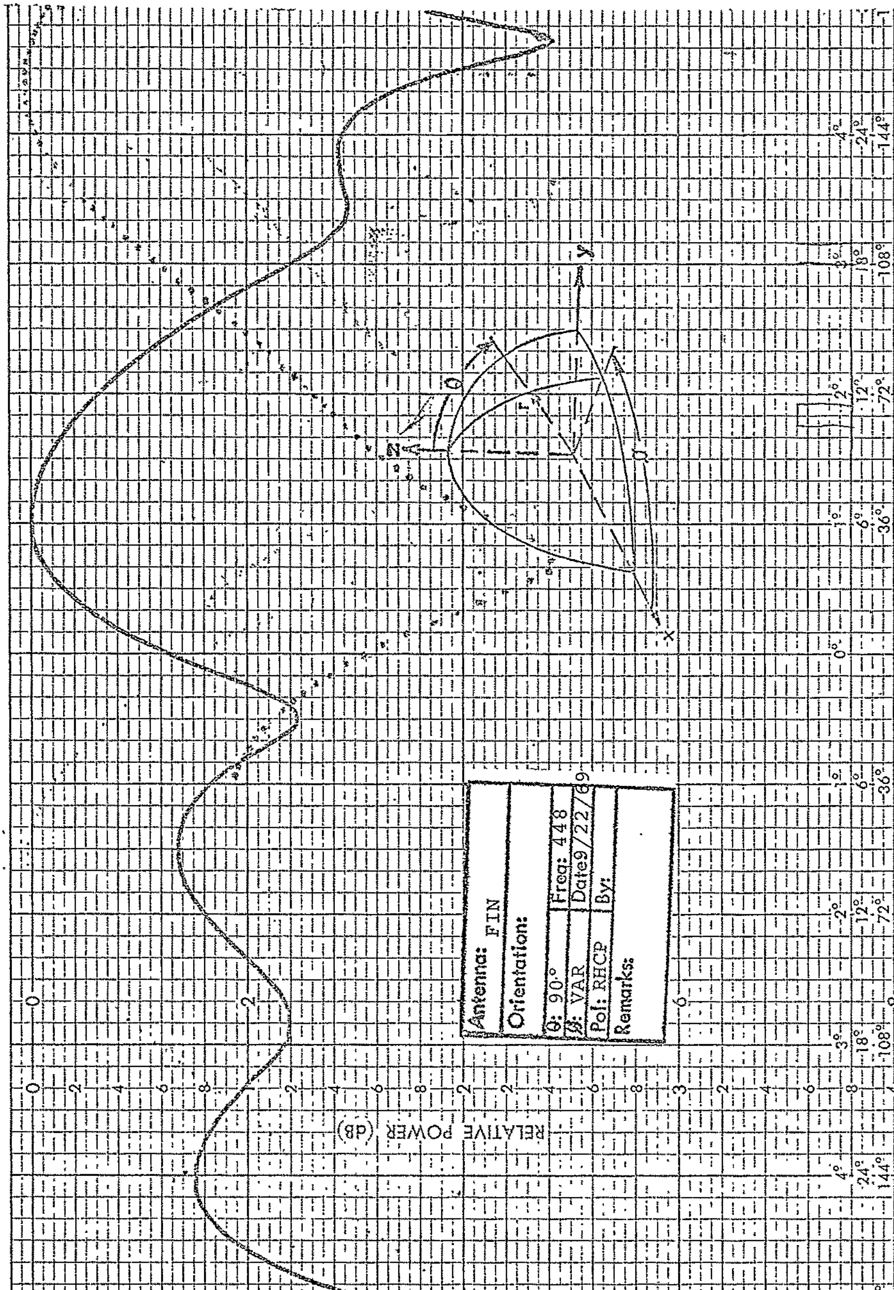


Figure 42. Pattern of Fin With Open Top, λ/4 From Parasite, Circular Polarization

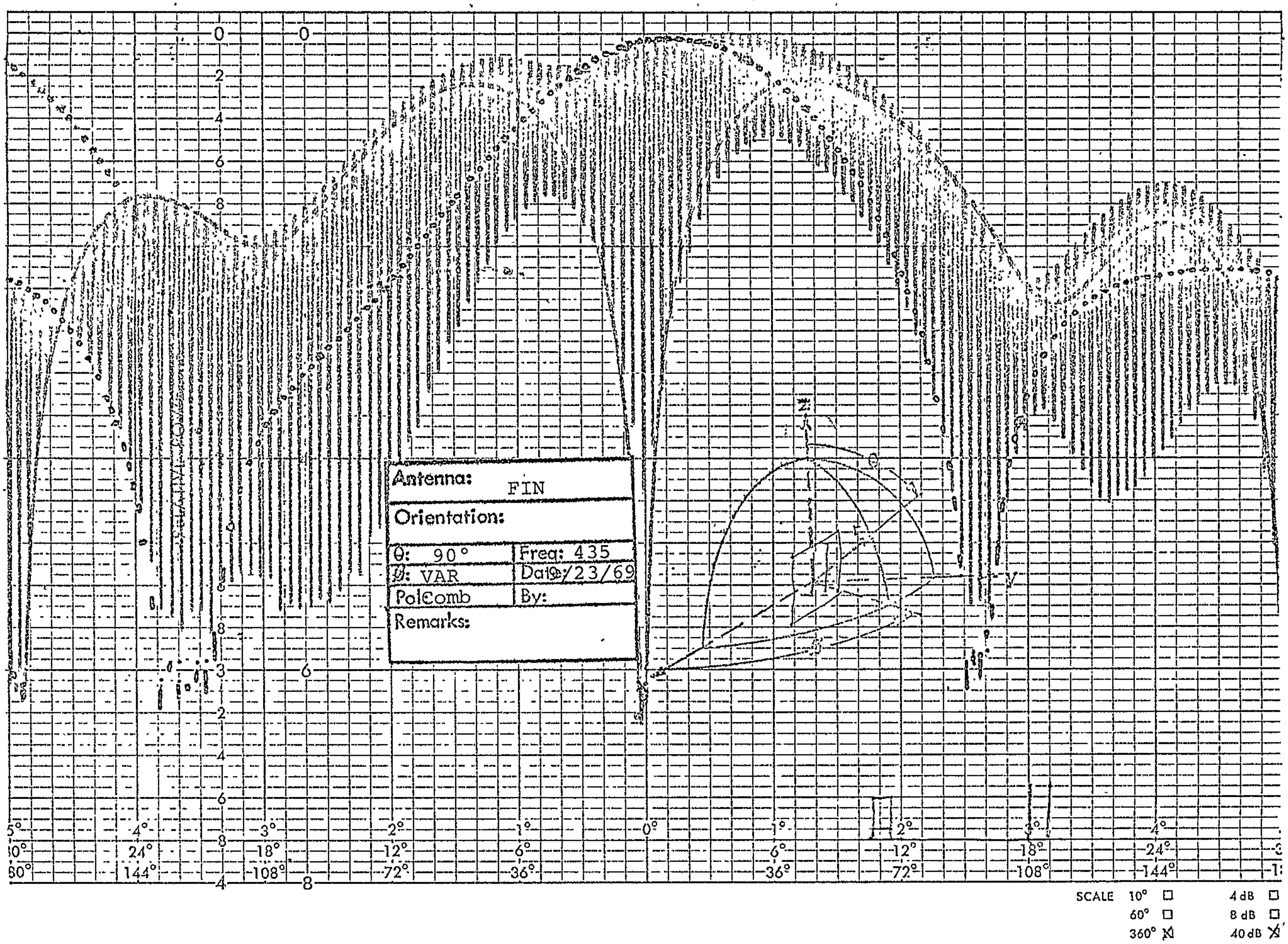


Figure 43. Pattern of Fin With Open Top, λ/4 From Reversed Parasite, Rotating Polarization

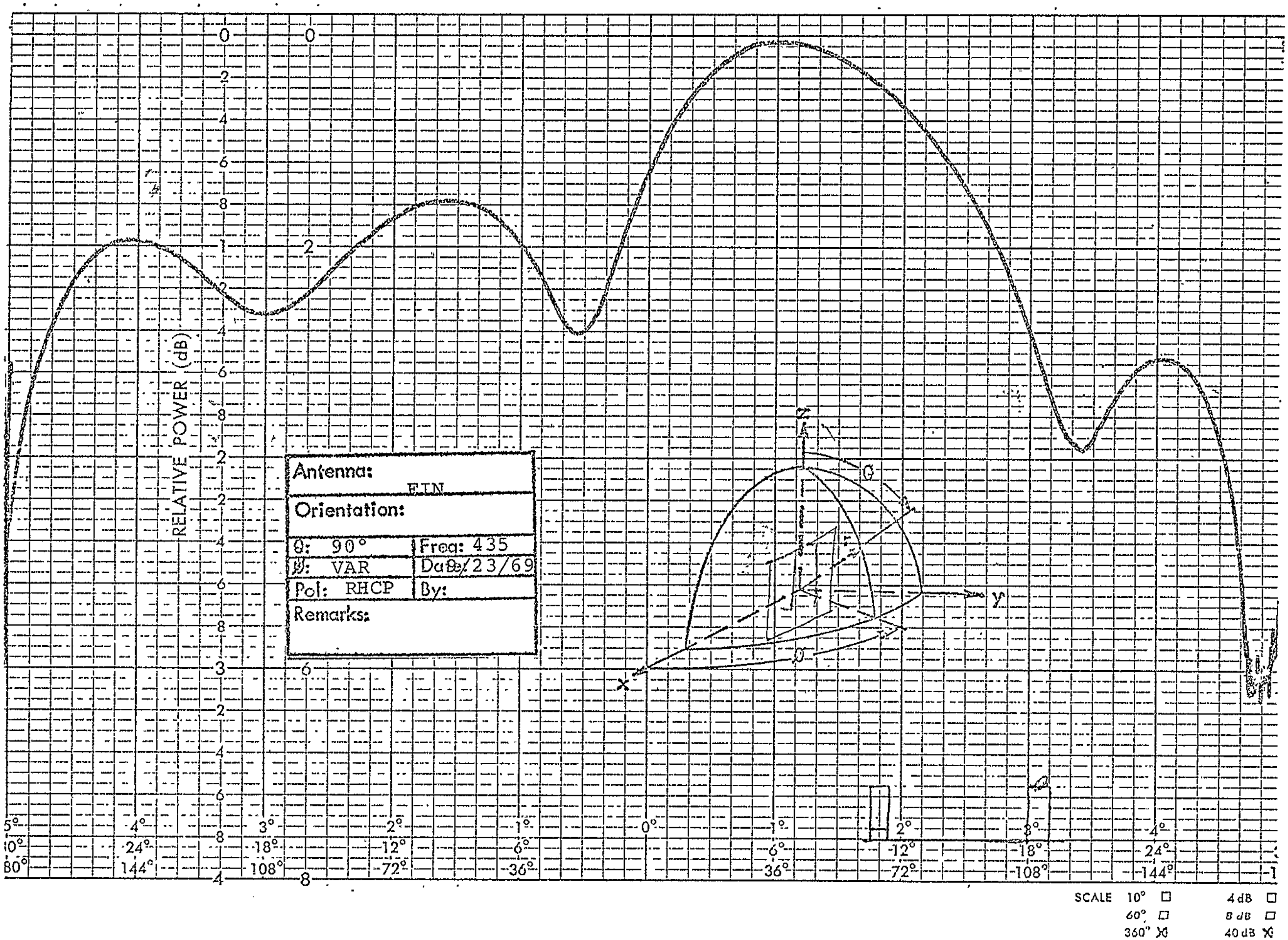


Figure 44. Pattern of Fin With Open Top, λ/4 From Reversed Parasite, Circular Polarization

2.5 Vee Fin

An attempt was made to get better axial ratio near zenith by constructing a vee type fin and feeding the slot of the vee. The pattern obtained by feeding the Vee near its Apex is shown in Figure 45. The patterns obtained by feeding the vee at its open end are shown in Figures 46 and 47. Note that for this configuration the circularly polarized pattern is again relatively symmetrical but the axial ratio is very poor.

An attempt was then made to bend the vee to make the sides parallel. Patterns for this configurations are shown in Figures 48 through 51 for three different frequencies. None of these configurations produced satisfactory results. Two other configurations were also tried: a vee fin with a parasite fin in the vee and a vee formed by two fins at right angles. Patterns for these two cases are shown in Figures 52 -53 and 54-55 respectively. Neither of these configurations produced outstandings results. Attention was then focused on arrays of two fins.

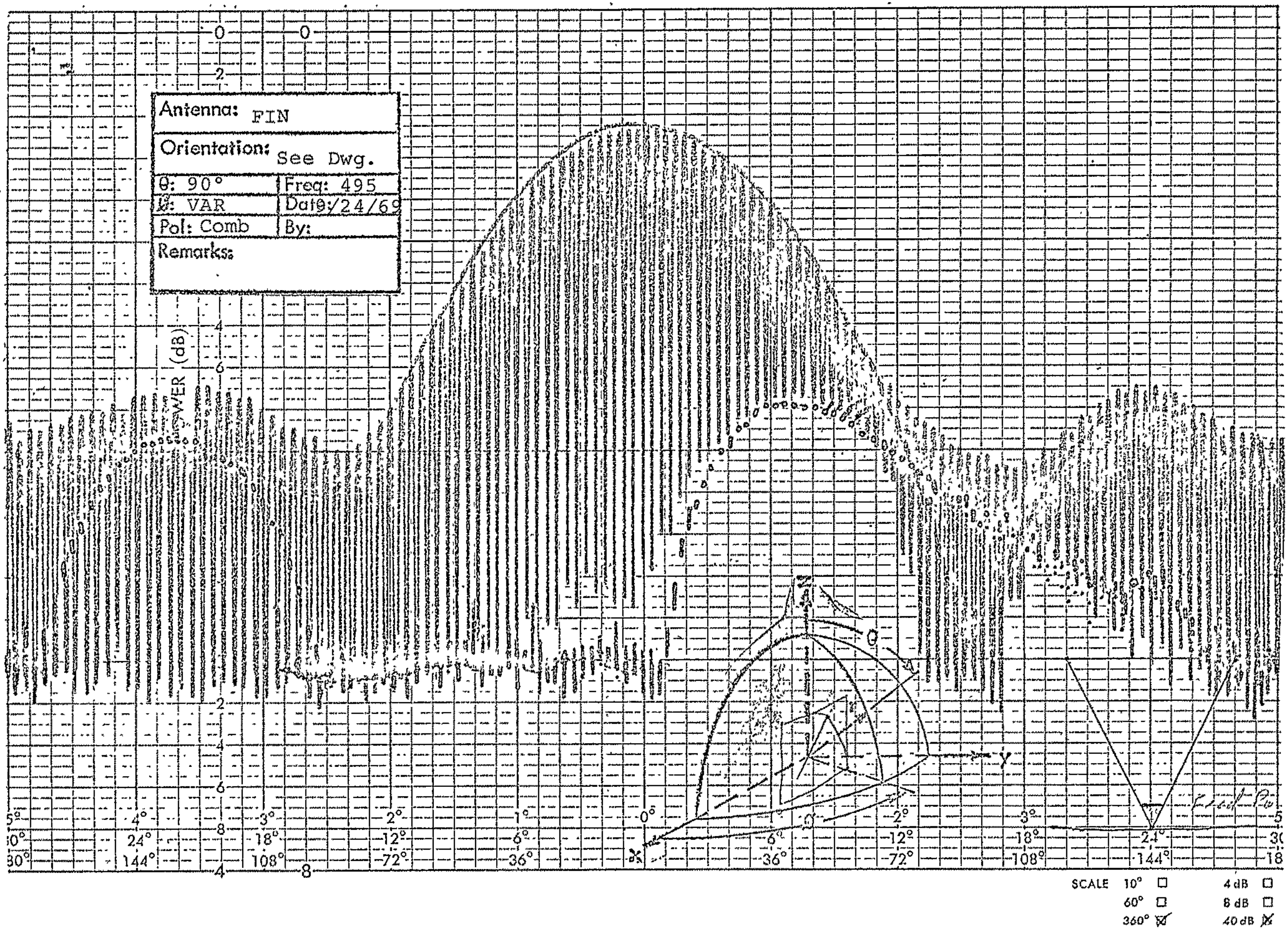


Figure 45. Pattern of Vee Fin Fed At Apex

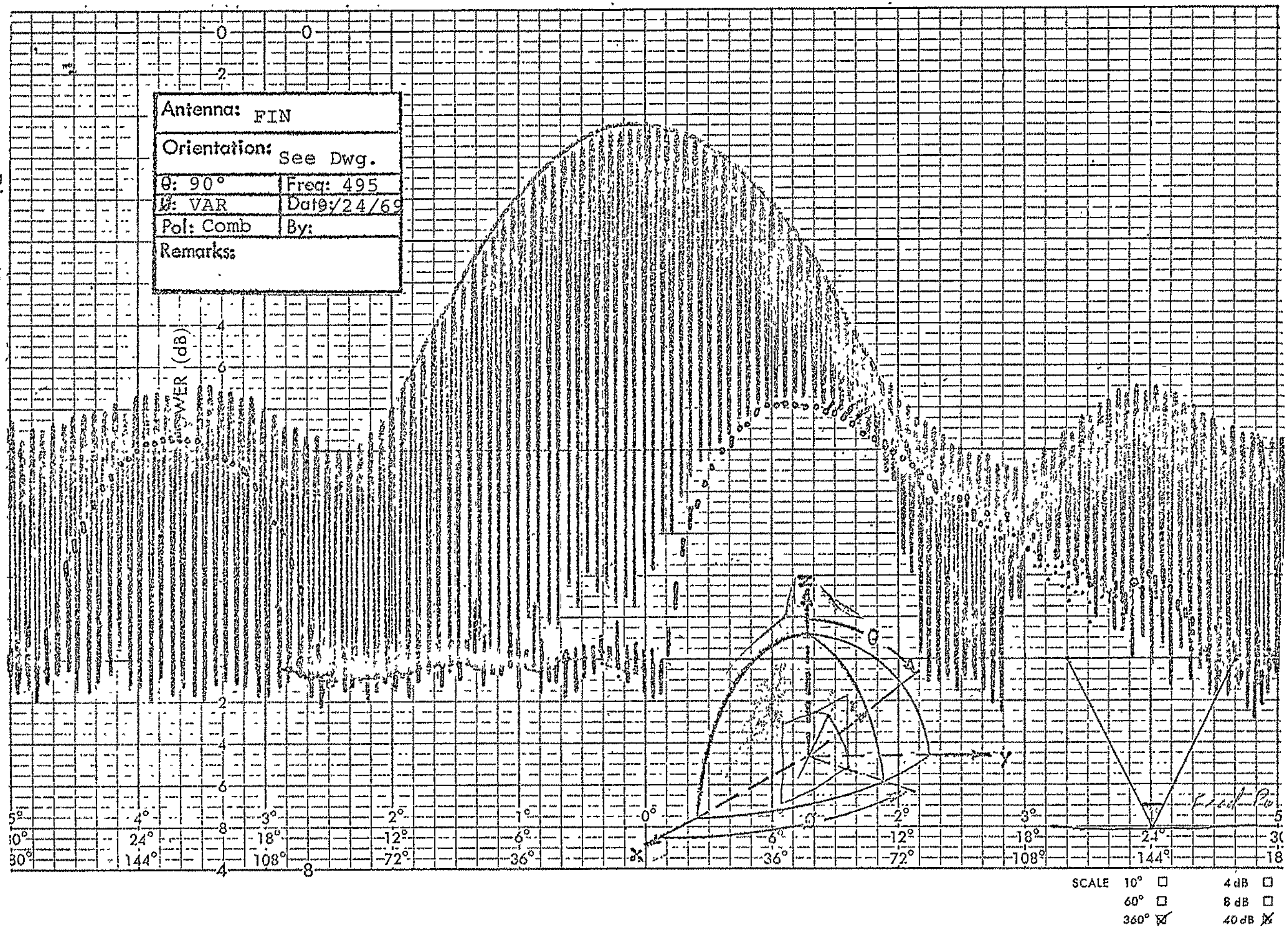


Figure 45. Pattern of Vee Fin Fed At Apex

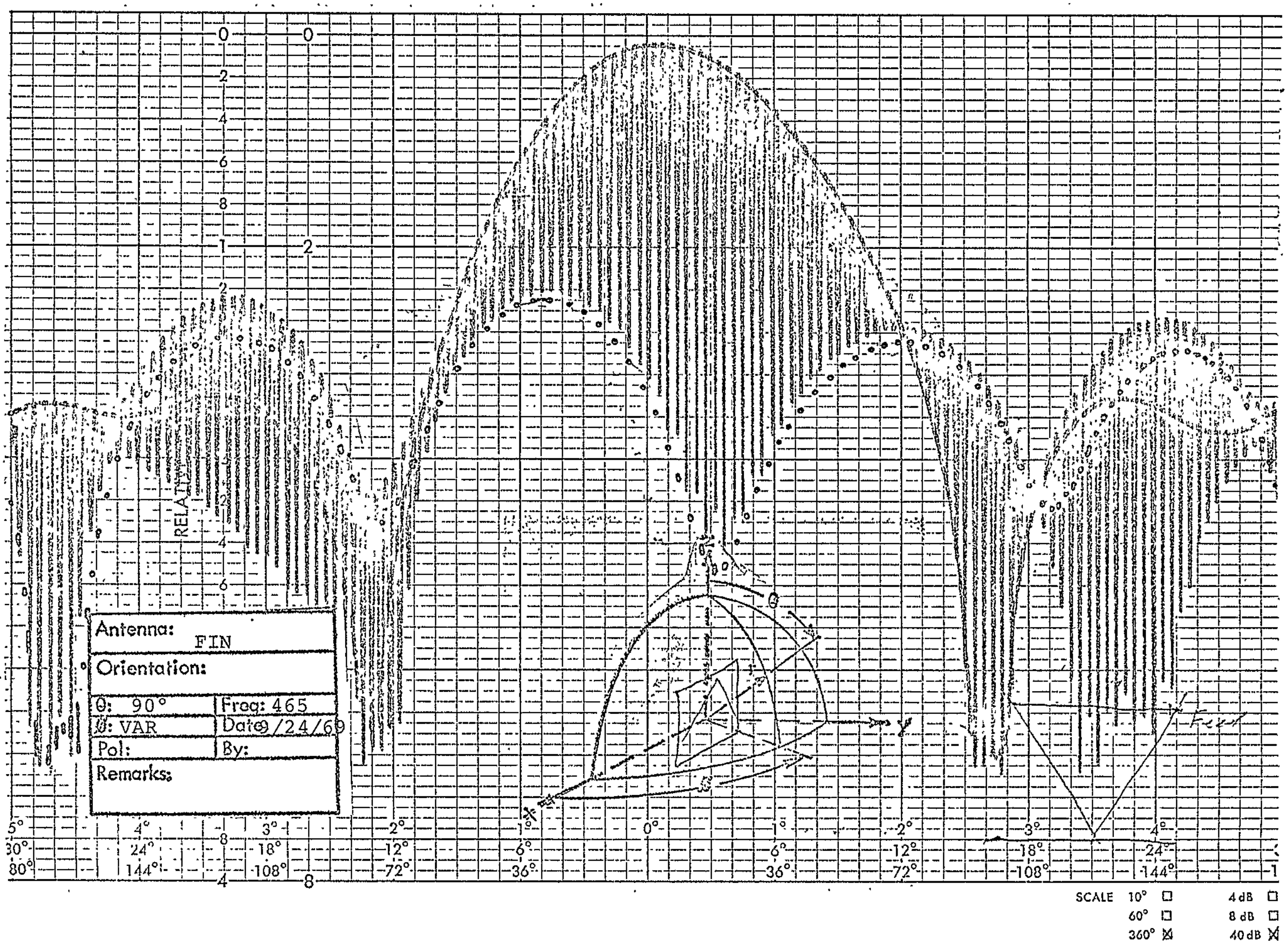


Figure 46. Pattern of Vee Fed At Open End, Rotating Polarization

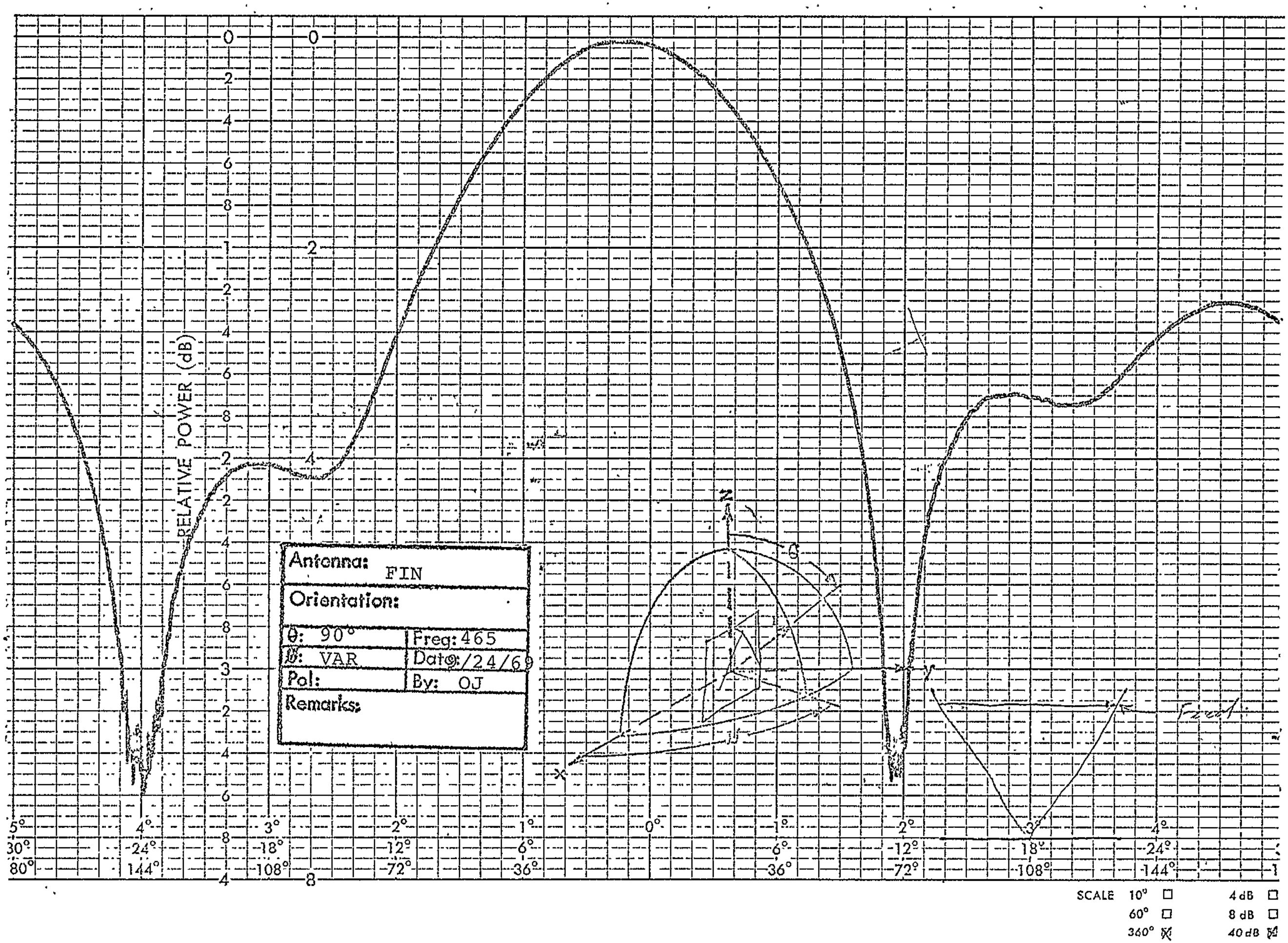


Figure 47. Pattern of Vee Fin Fed At Open End, Circular Polarization

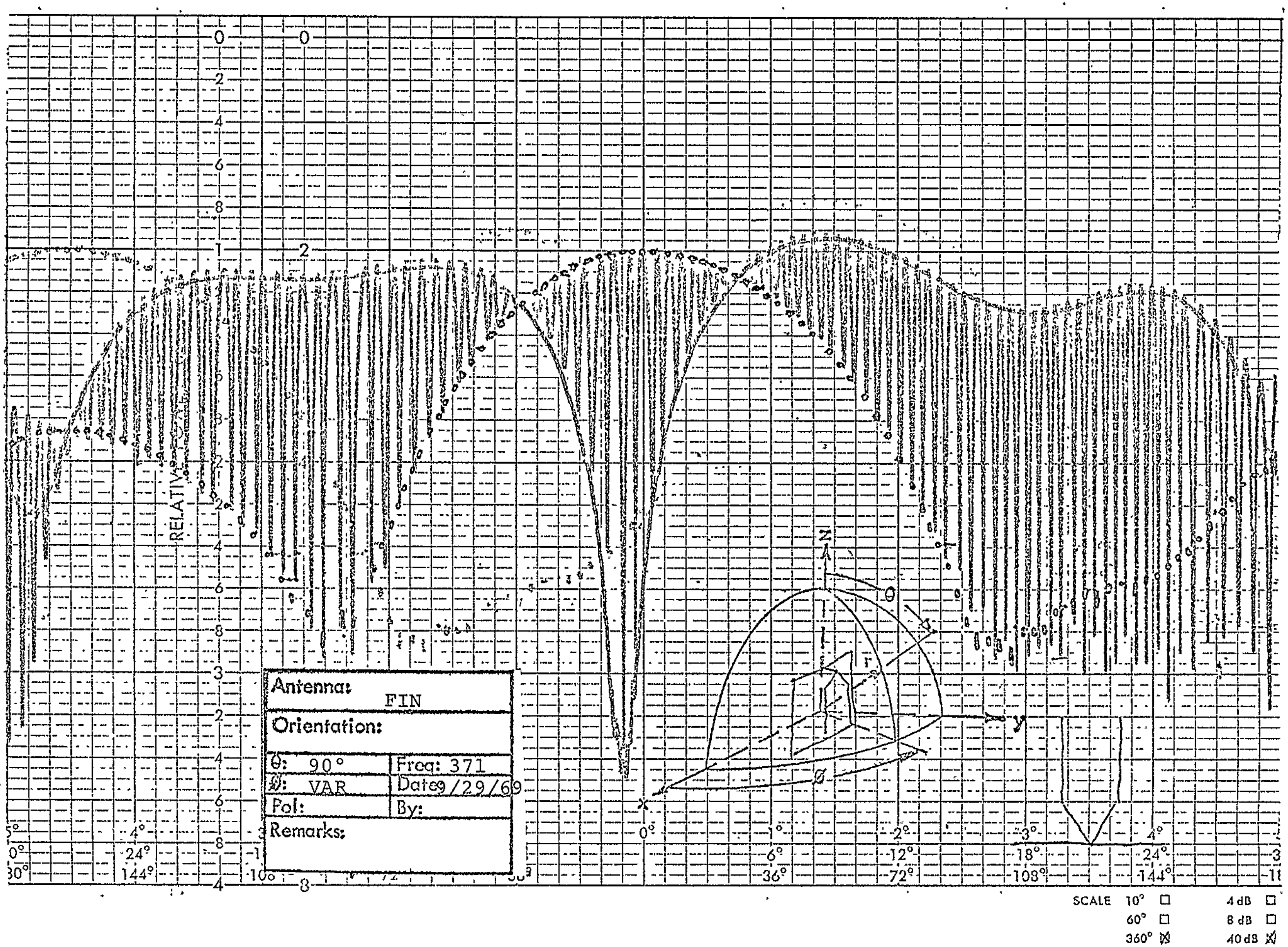


Figure 48. Pattern of Vee Fin With Bent Arms, Rotating Polarization, 371 MHz

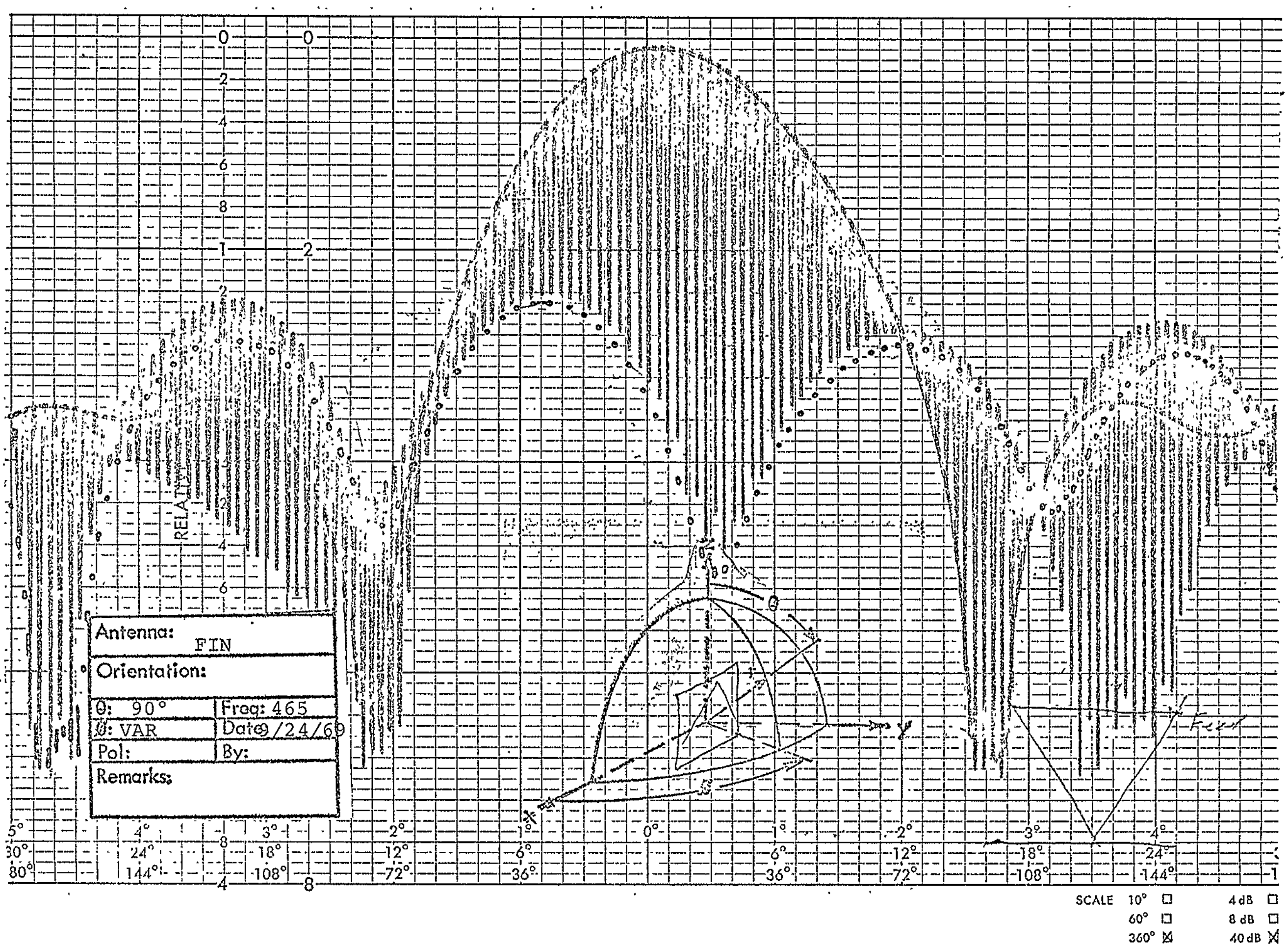
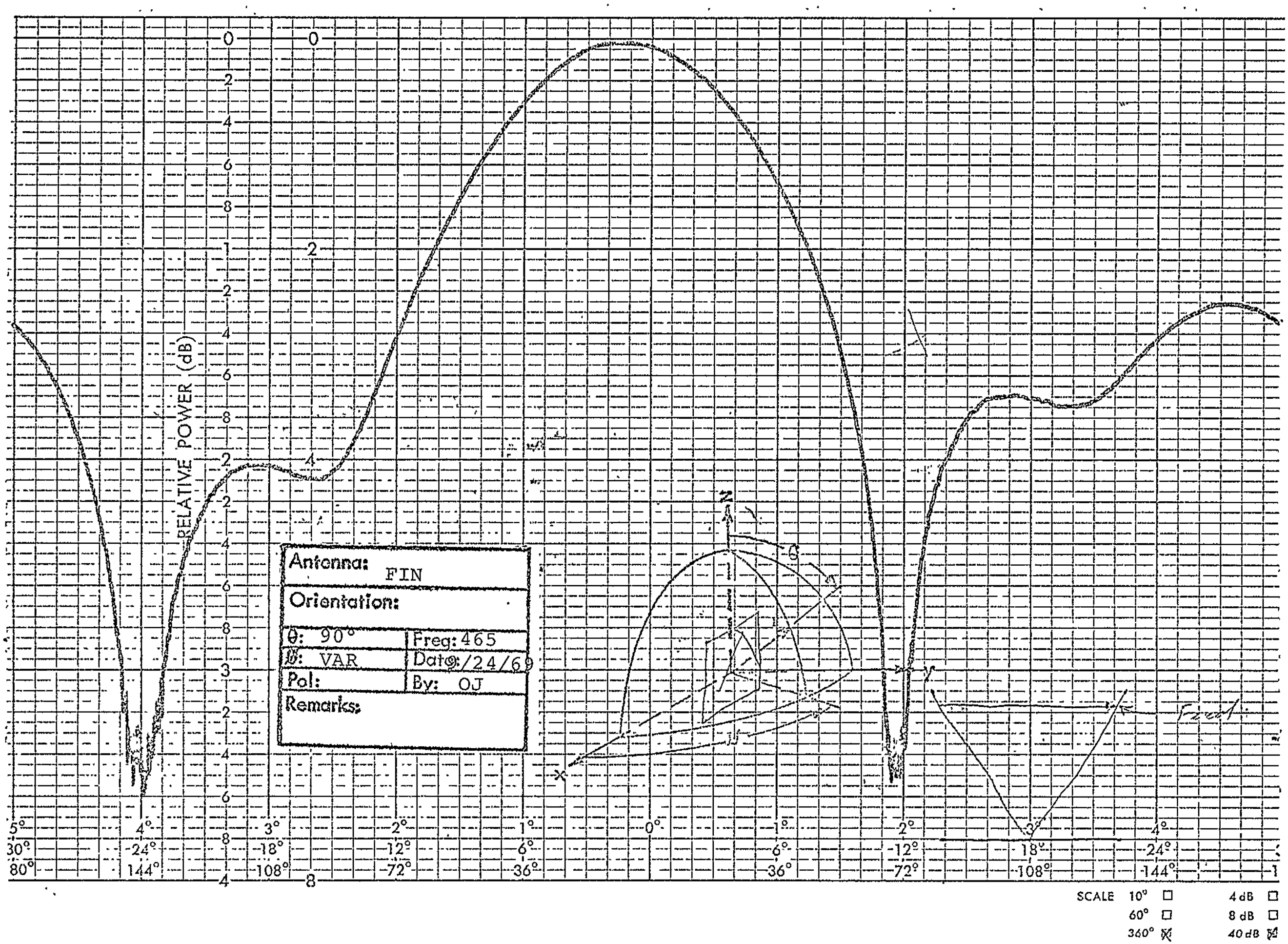


Figure 46. Pattern of Vee Fed At Open End, Rotating Polarization

Figure 47. Pattern of Vee Fin Fed At Open End,
Circular Polarization



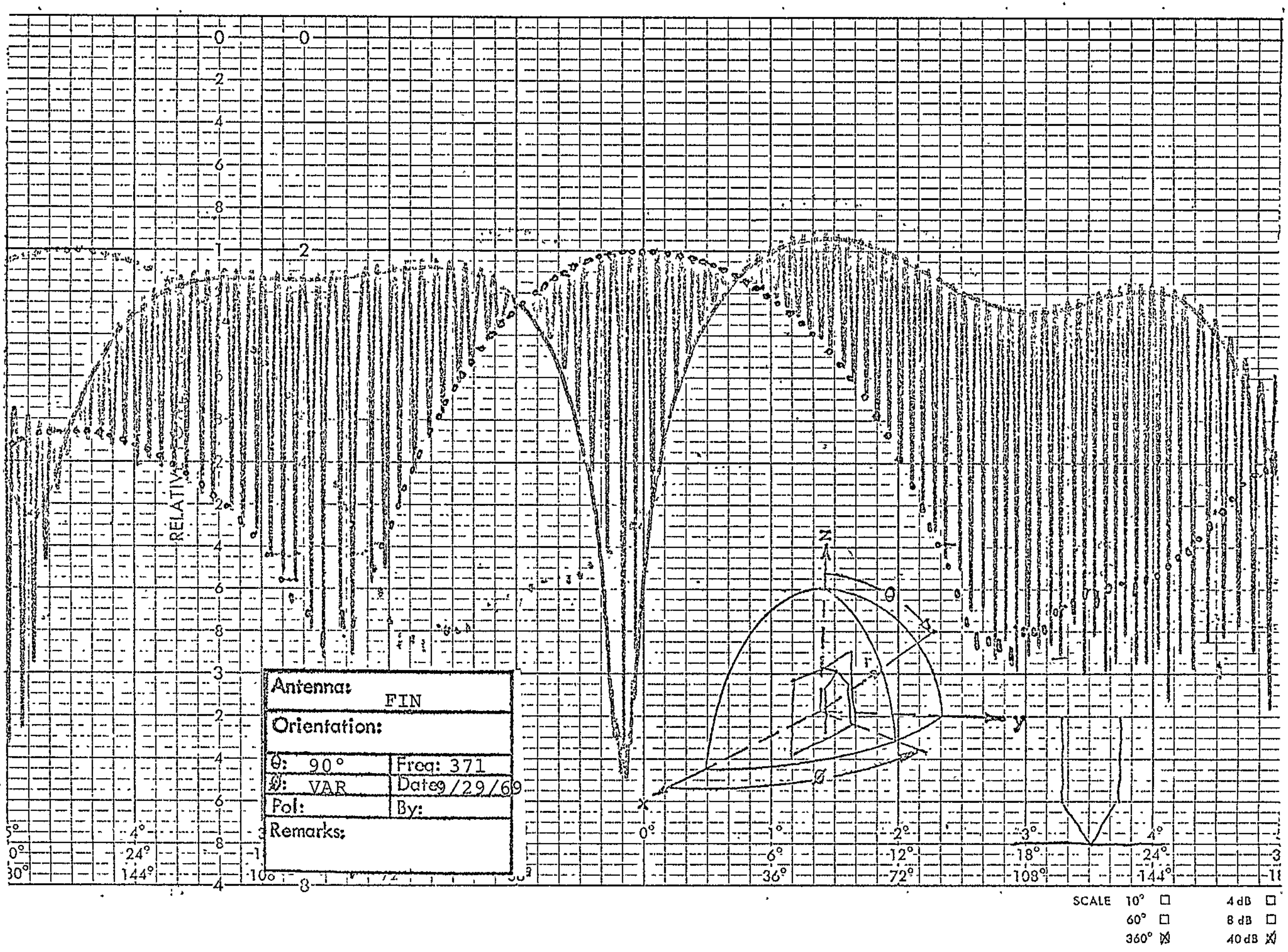


Figure 48. Pattern of Vee Fin With Bent Arms, Rotating Polarization, 371 MHz

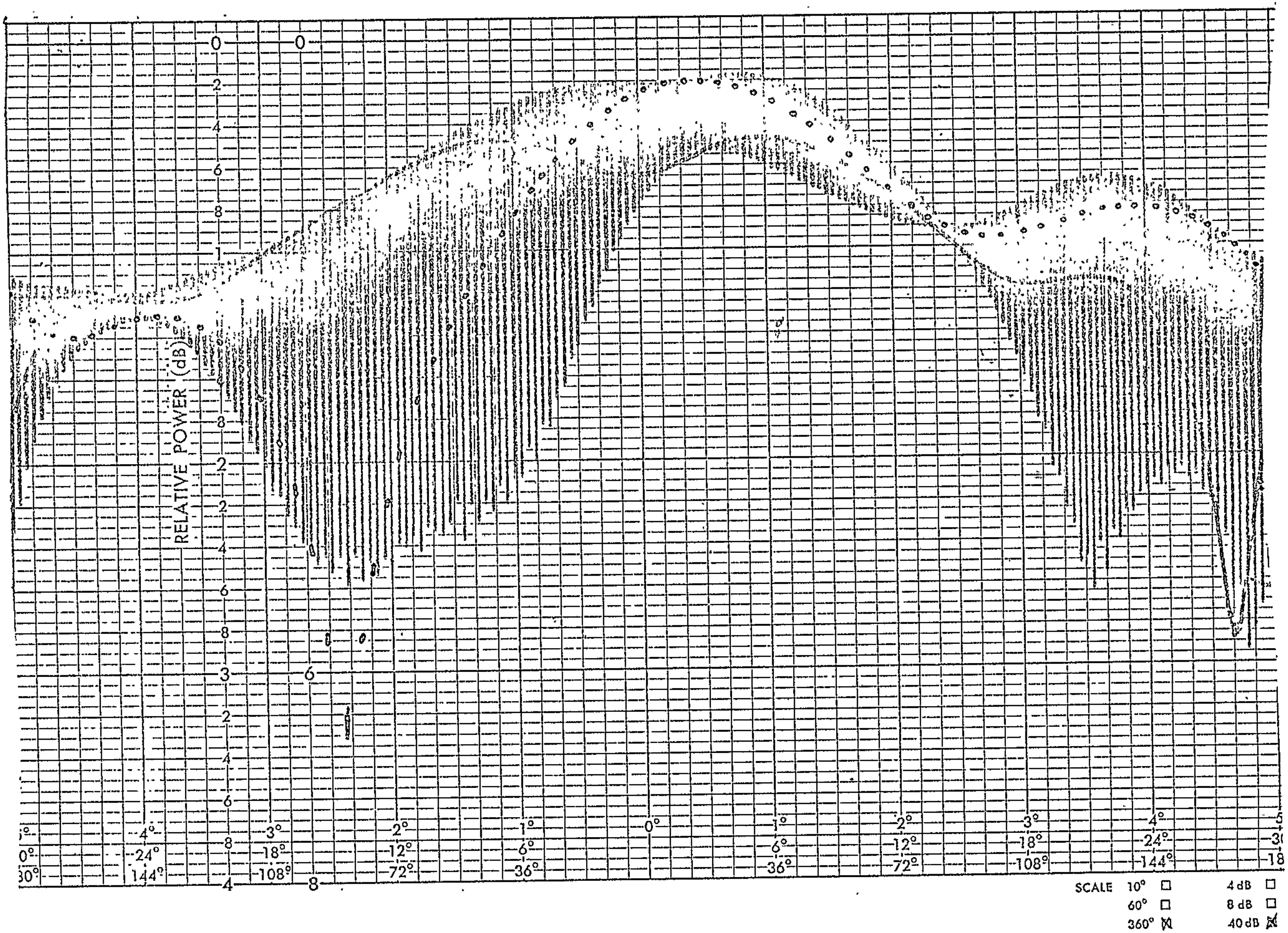


Figure 54. Pattern of Two Fins at 90° Angle,
Rotating Polarization

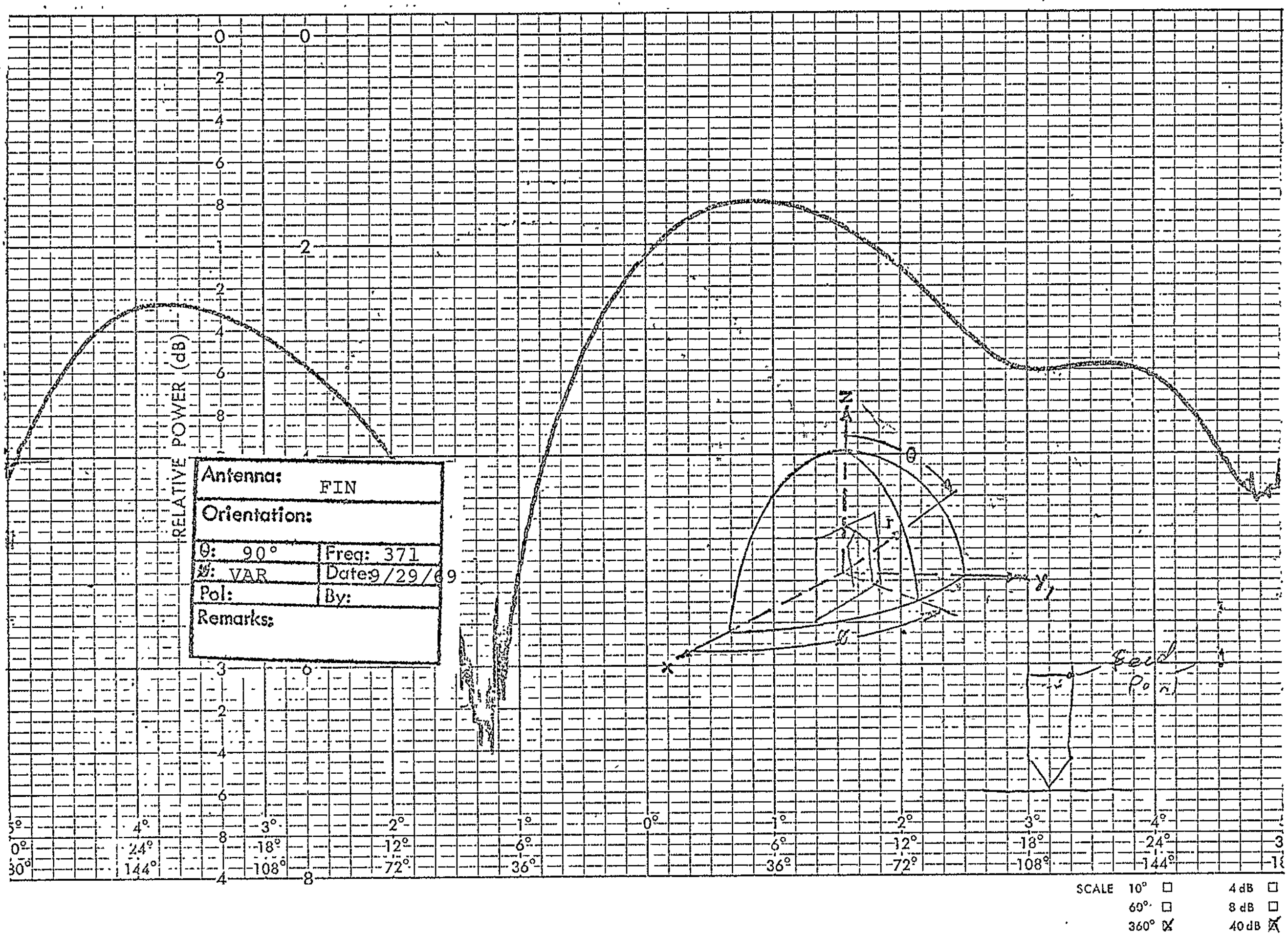


Figure 49. Pattern of Vee Fin With Bent Arms, Circular Polarization, 475 MHz

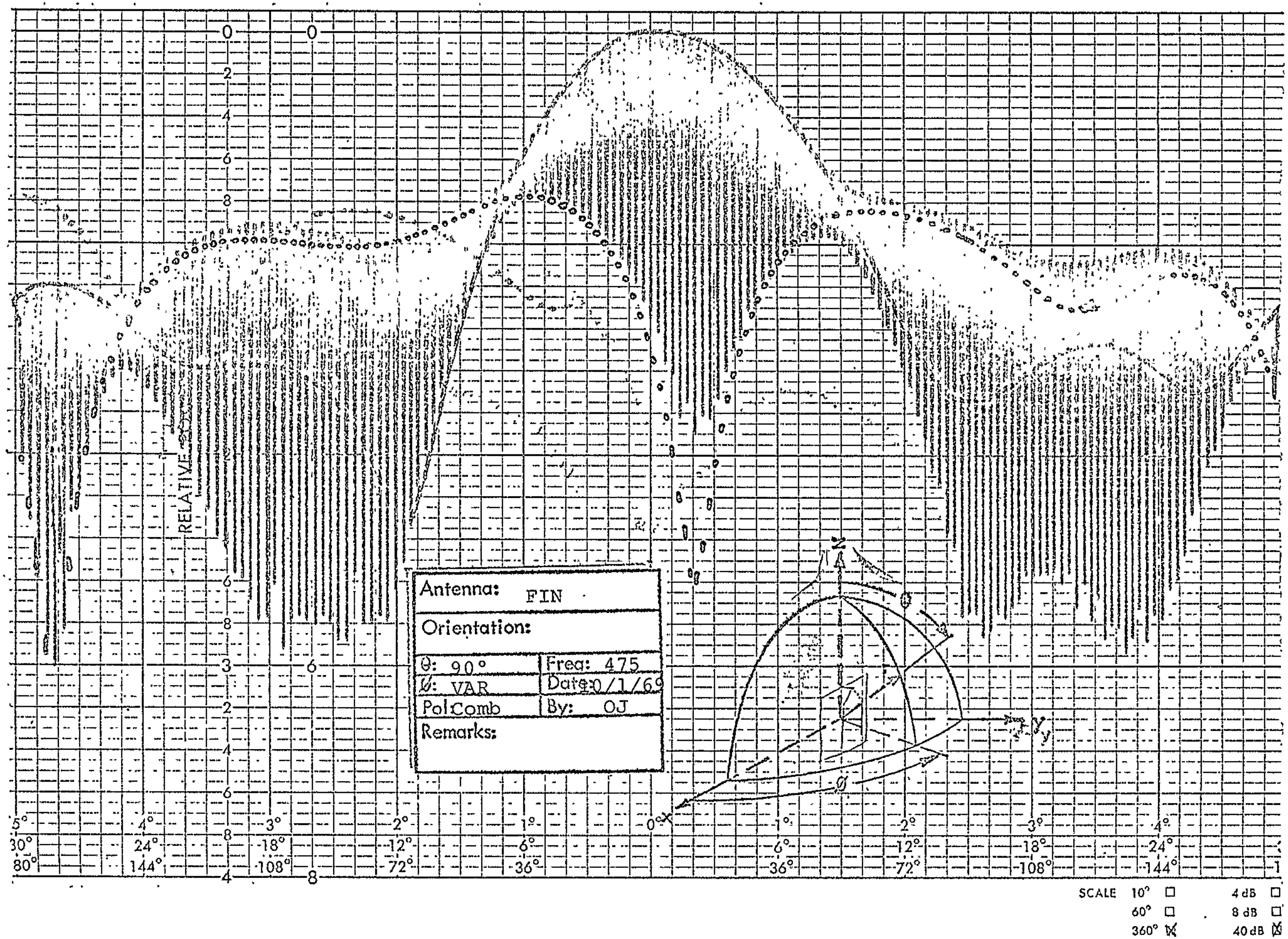


Figure 50. Pattern of Vee Fin With Bent Arms, Rotating Polarization, 475 MHz

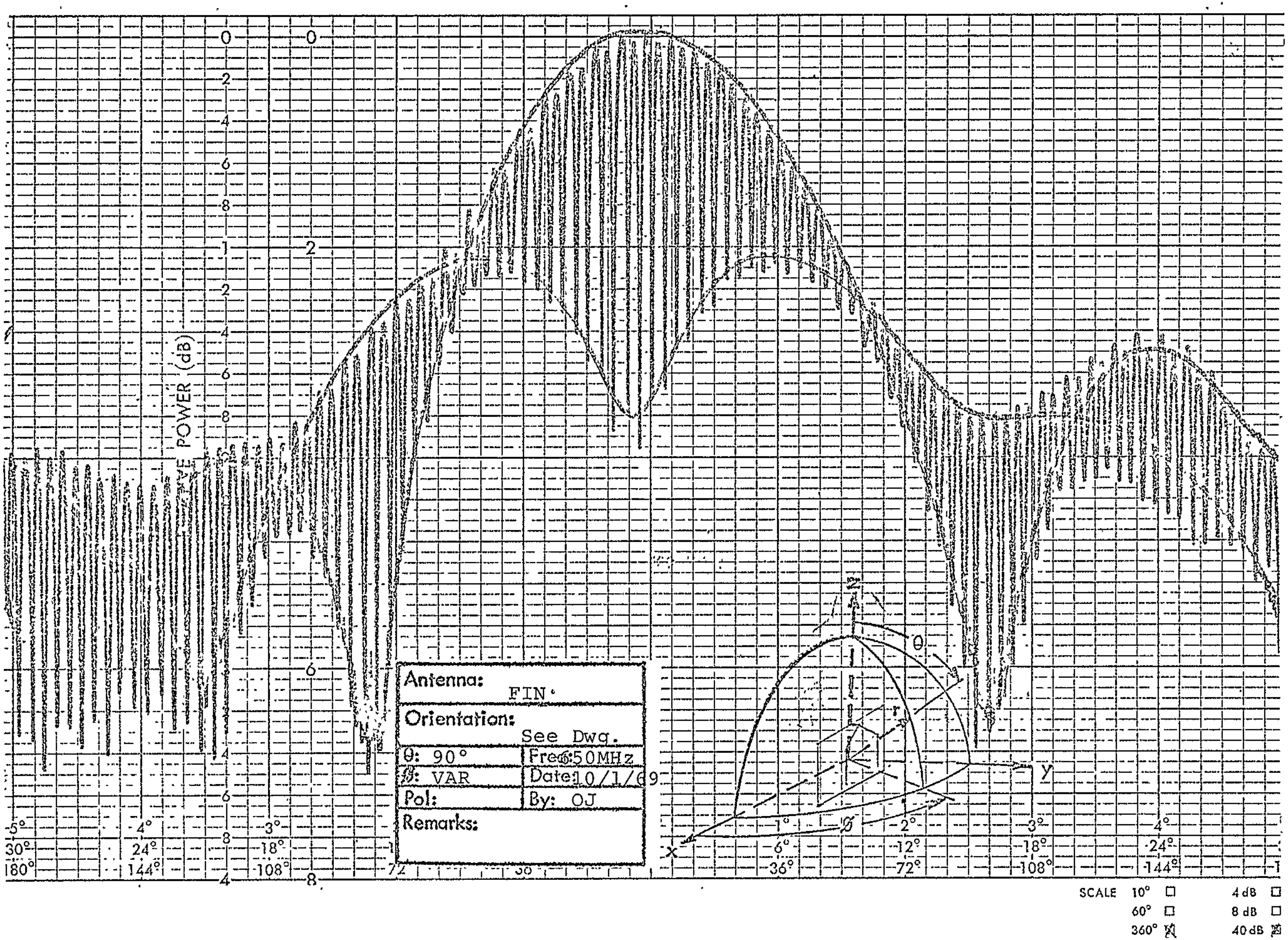


Figure 51. Pattern of Vee Fin With Bent Arms, Rotating Polarization, 650 MHz

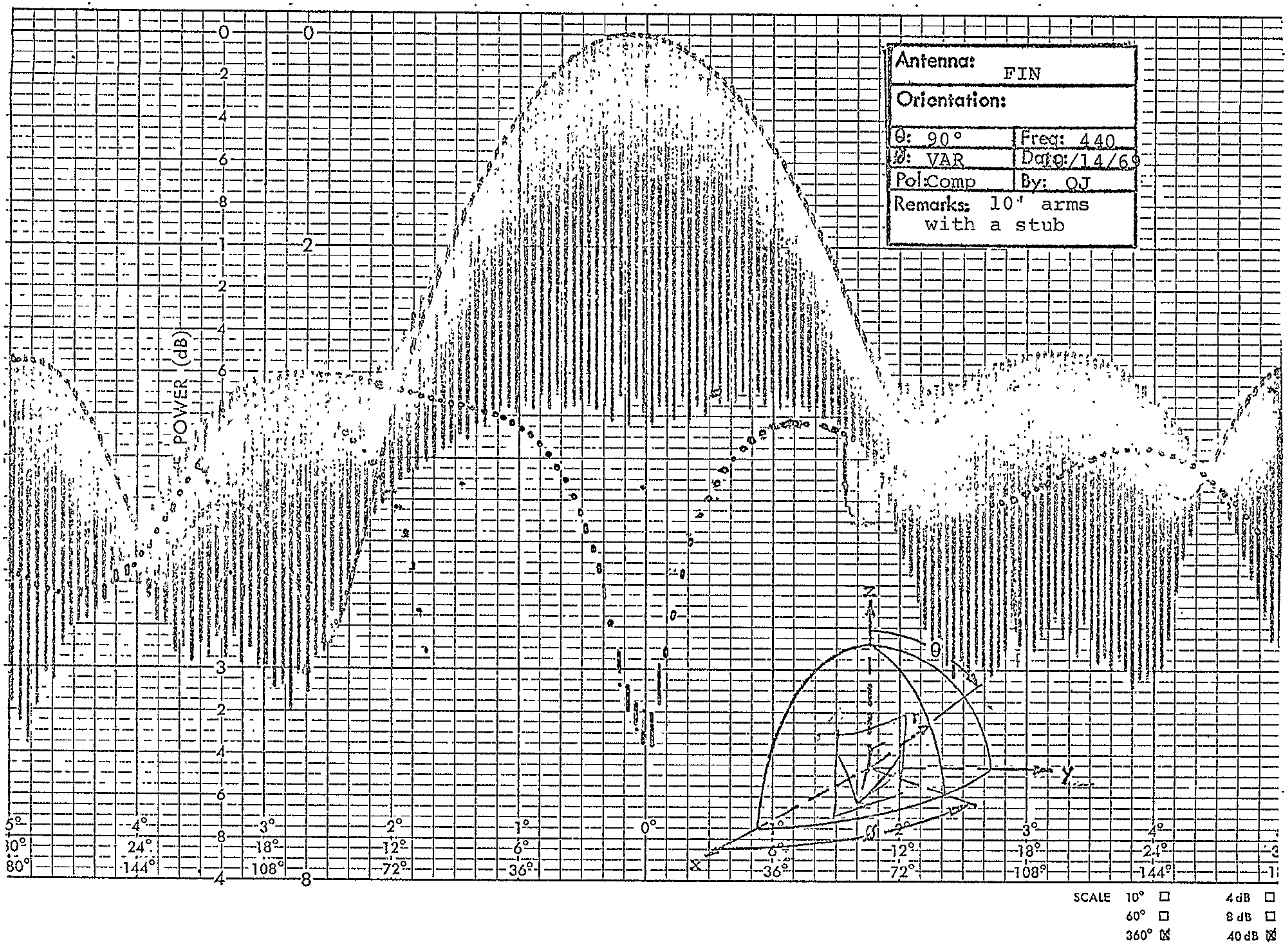


Figure 52. Pattern of Vee Fin With Parasite Fin, Rotating Polarization

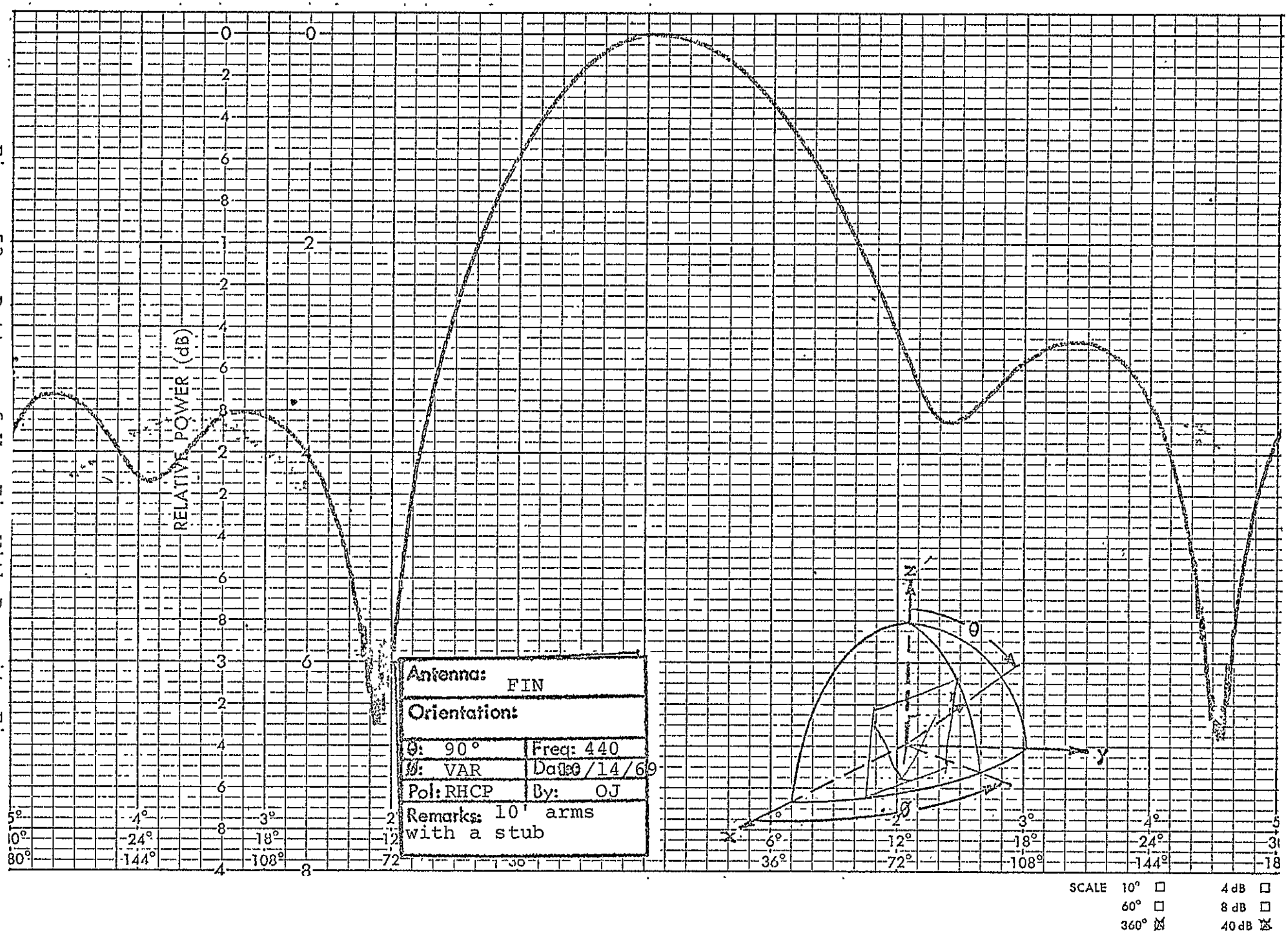


Figure 53. Pattern of Vee Fin With Parasite Fin, Circular Polarization

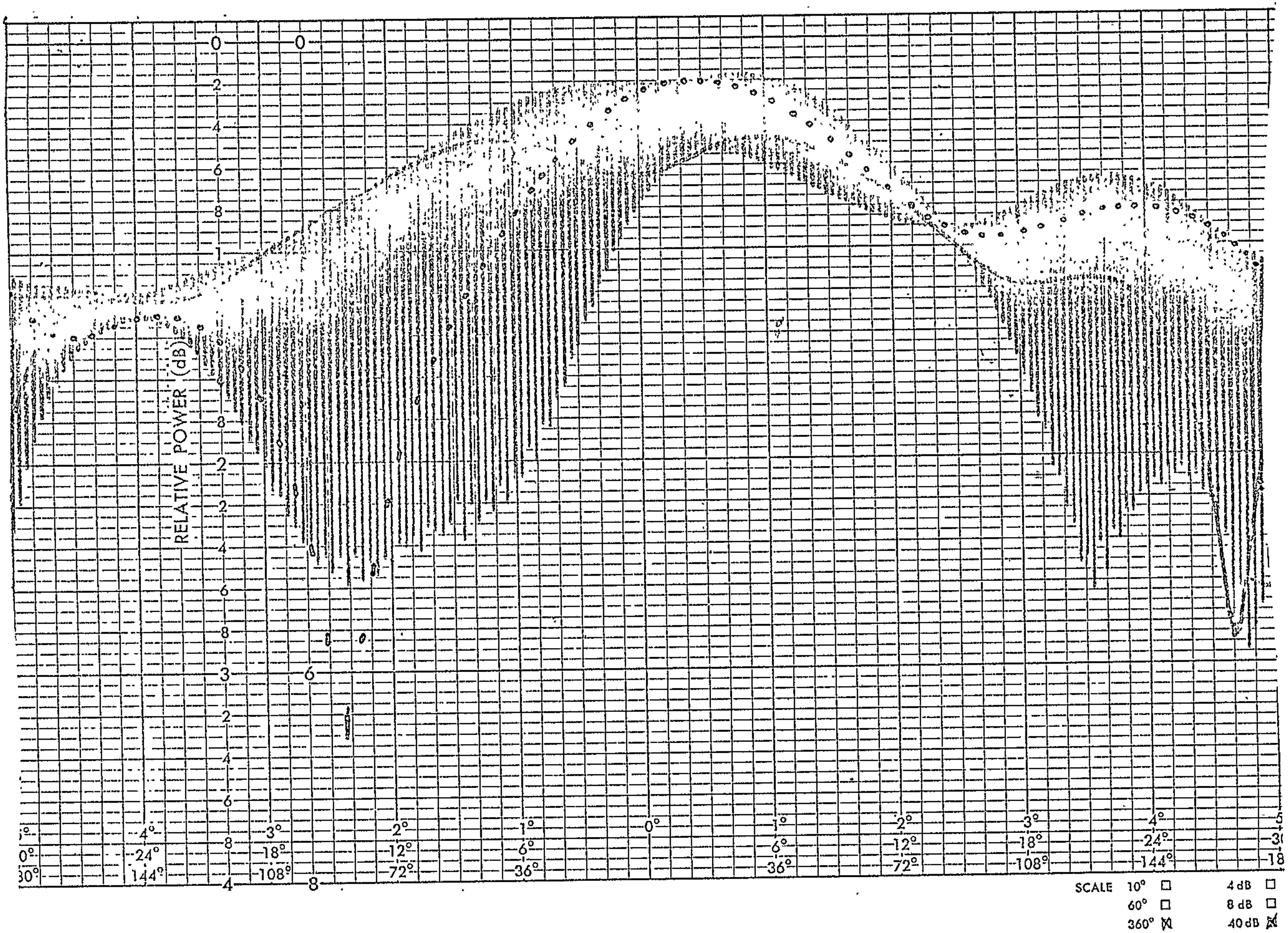


Figure 54. Pattern of Two Fins at 90° Angle, Rotating Polarization

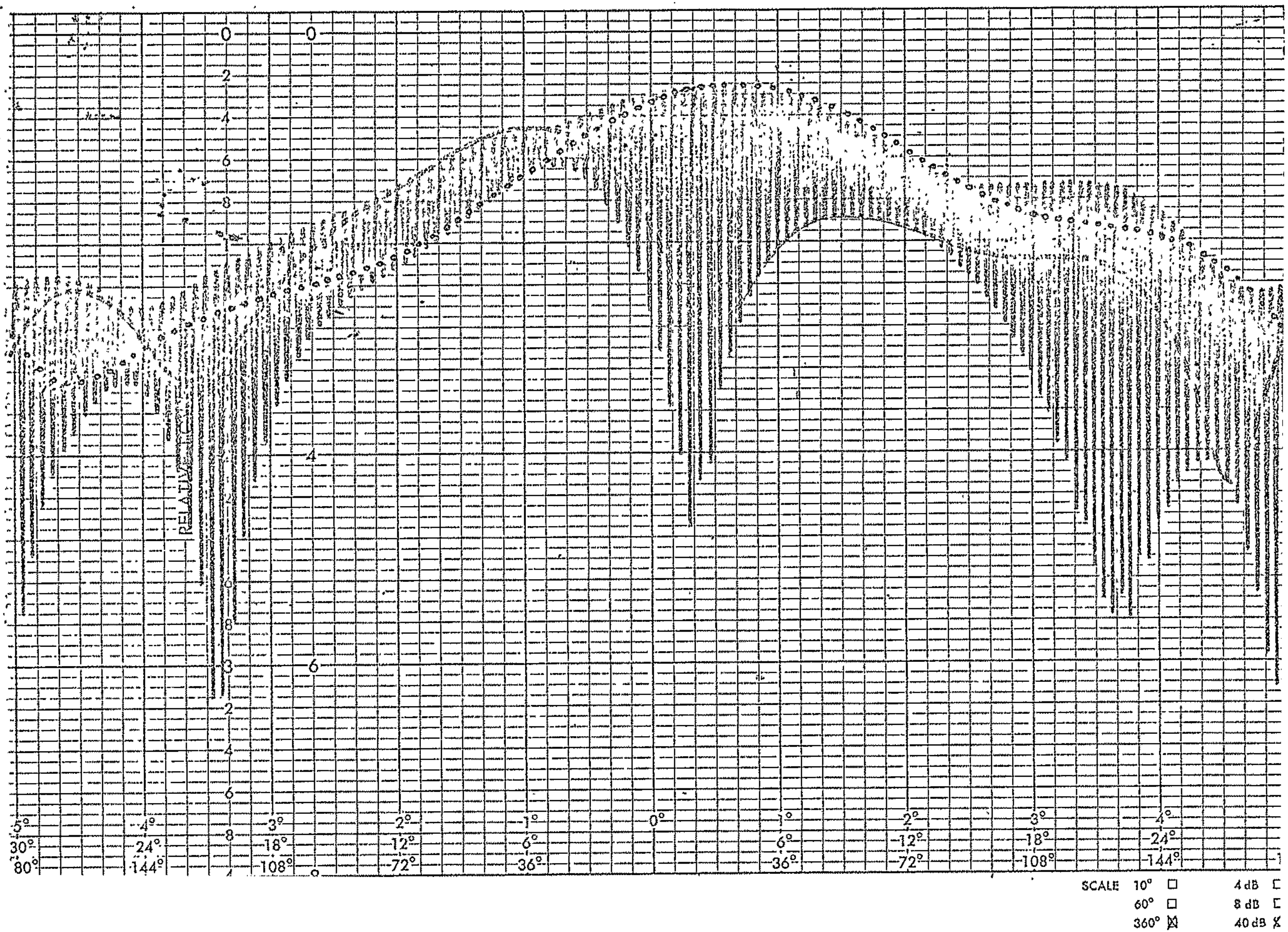


Figure 55. Pattern of Two Fins at 90° Angle, Circular Polarization

2.6 Double Fin

The patterns of two fins spaced a quarter wavelength apart are shown in Figures 56 and 57. These are similar to the patterns of Figures 31 and 32. These two fins were then fed 90° out of phase. The resulting patterns are shown in Figures 58 and 59. Patterns for the same two fins fed in phase are shown in Figures 60 and 61. Next one fin was reversed and patterns repeated for parasitic and in-phase feeding. Patterns for these two cases are shown in Figures 62-63 and 64-65 respectively.

Next two separate fins were constructed, one tuned for 401.5 MHz and the other tuned for 466 MHz. These were fed in parallel and patterns were taken at the two frequencies. The results are shown in Figures 66 through 69. The circular patterns of Figures 67 and 69 show improved symmetry about the zenith with the lower frequency performance being somewhat better. Finally the two fins were reversed the results for this case are plotted in Figures 70 and 71. These patterns have somewhat better circularity, and the measured gain was 3.75db. at 401 MHz and 3.25db. at 466 MHz. A prototype antenna with these characteristics was taken to Goddard Space Flight Center and was successfully interrogated by the Nimbus satellite. Based on these satisfactory results a final model was fabricated, tested and delivered.

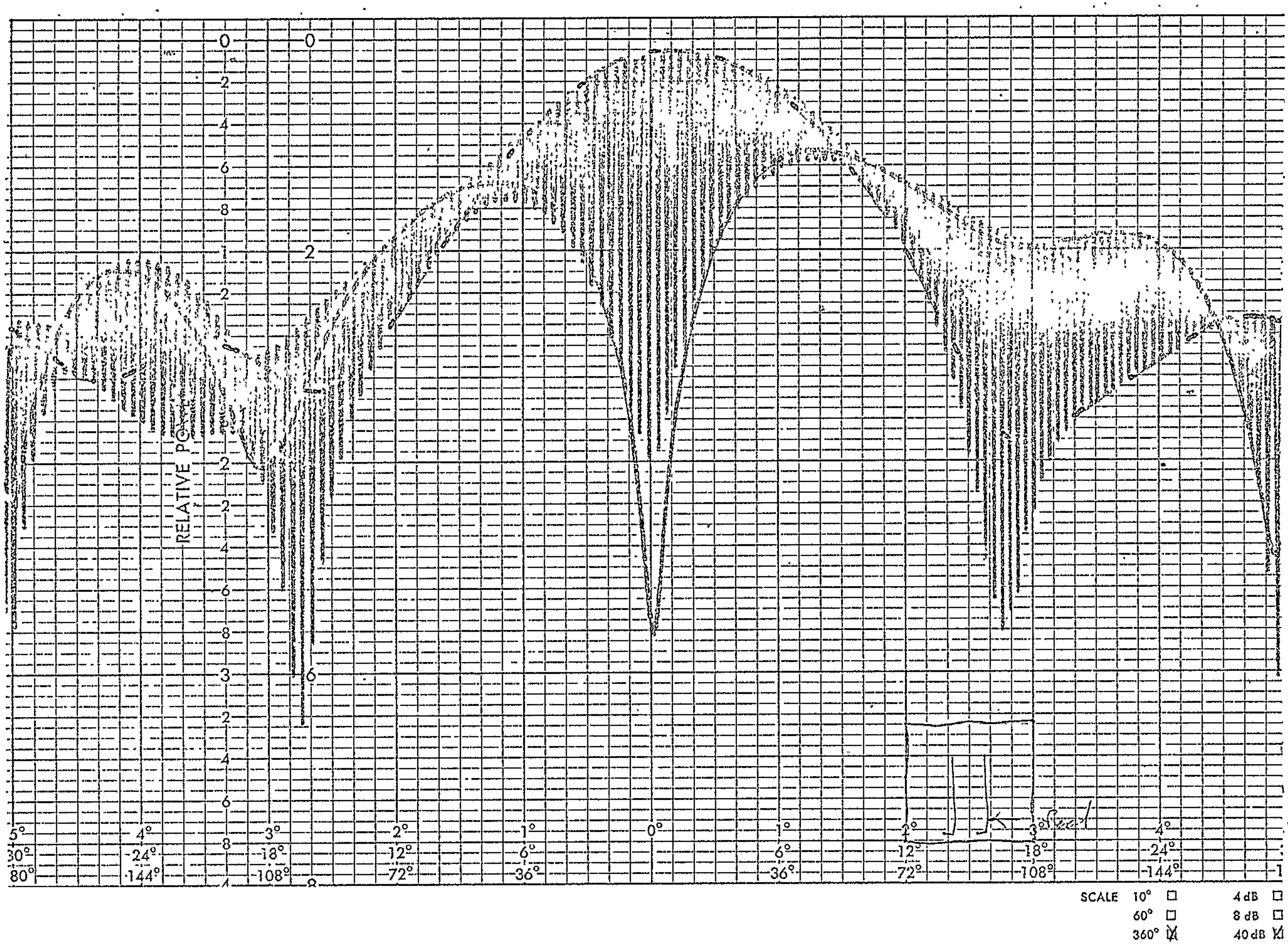


Figure 56. Pattern of Two Fins Spaced $\lambda/4$ Apart, Rotating Polarization

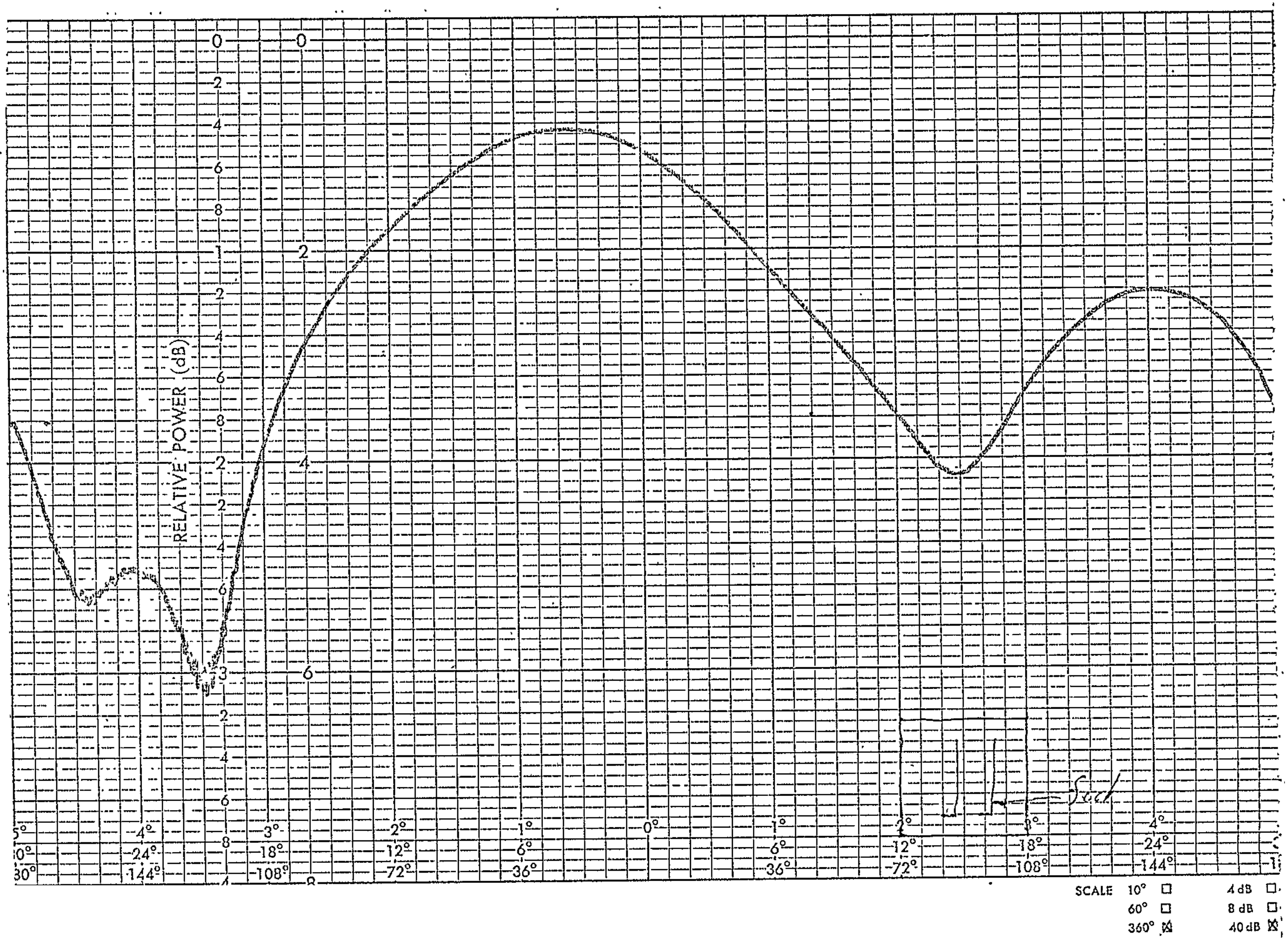


Figure 57. Pattern of Two Fins Spaced λ/4 Apart, Circular Polarization

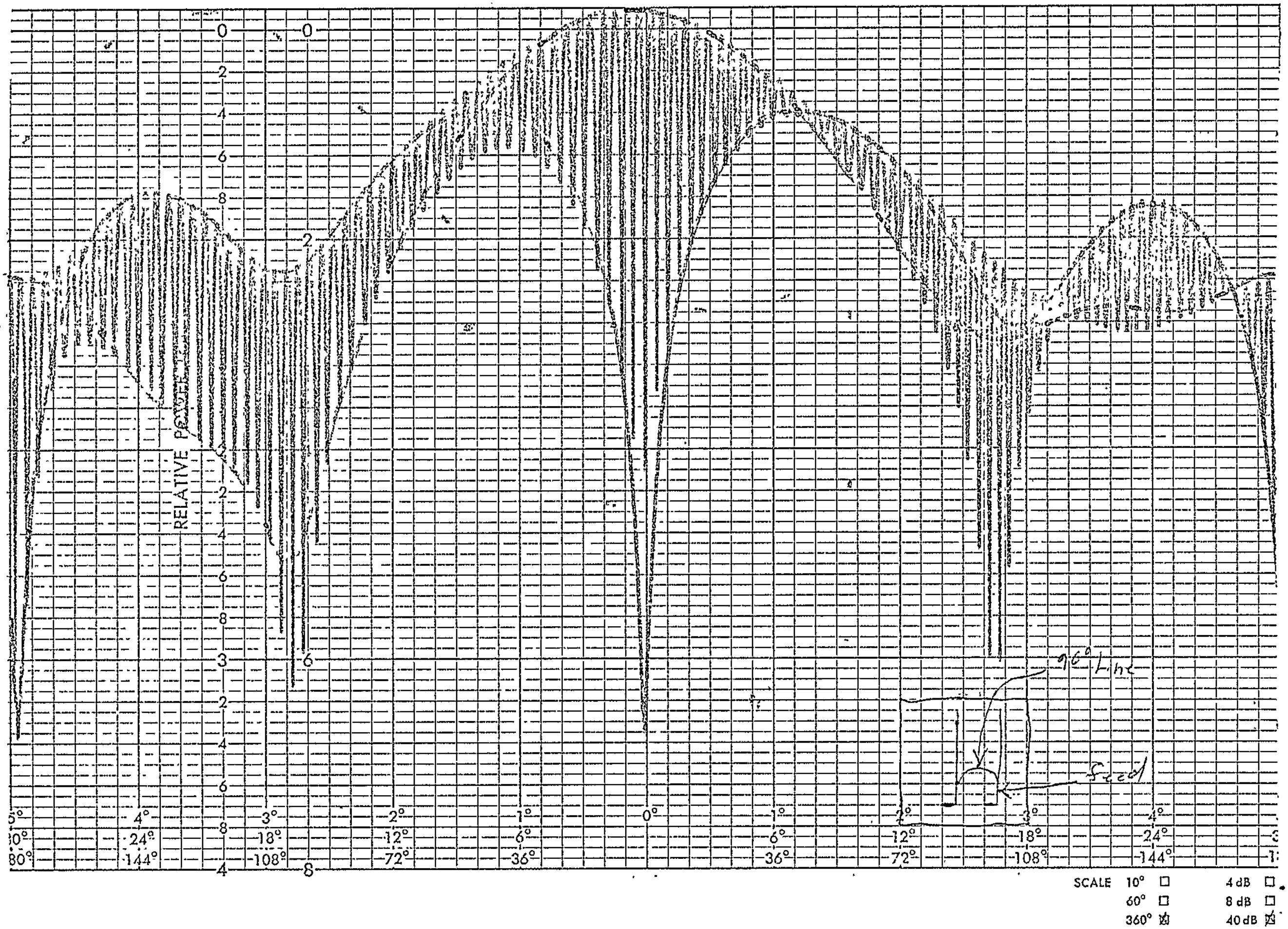


Figure 58. Pattern of Two Fins Spaced λ/4 Apart, Fed 90° Out of Phase, Rotating Polarization

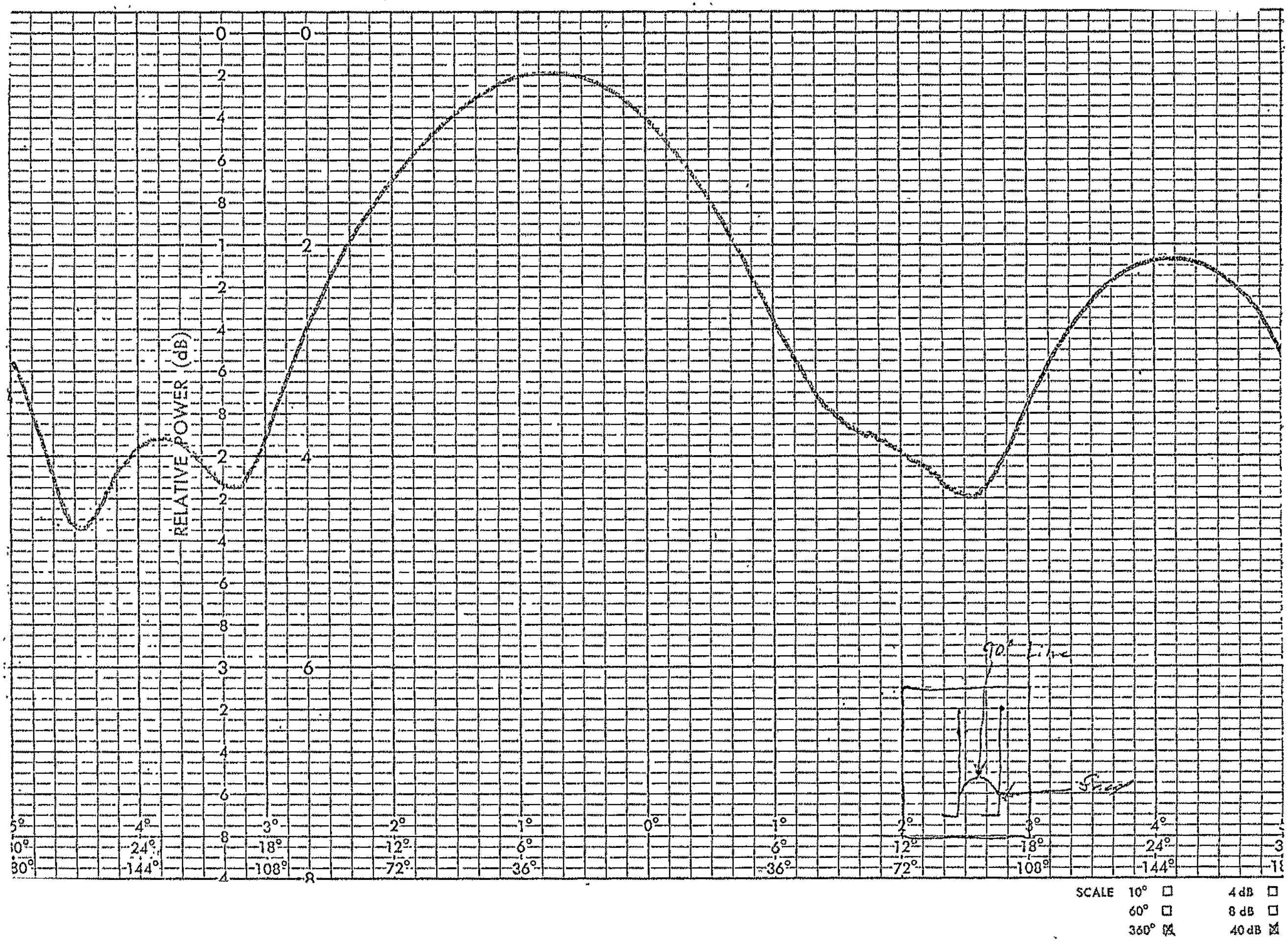


Figure 59. Pattern of Two Fins Spaced λ/4 Apart, Fed 90°
Out of Phase, Circular Polarization

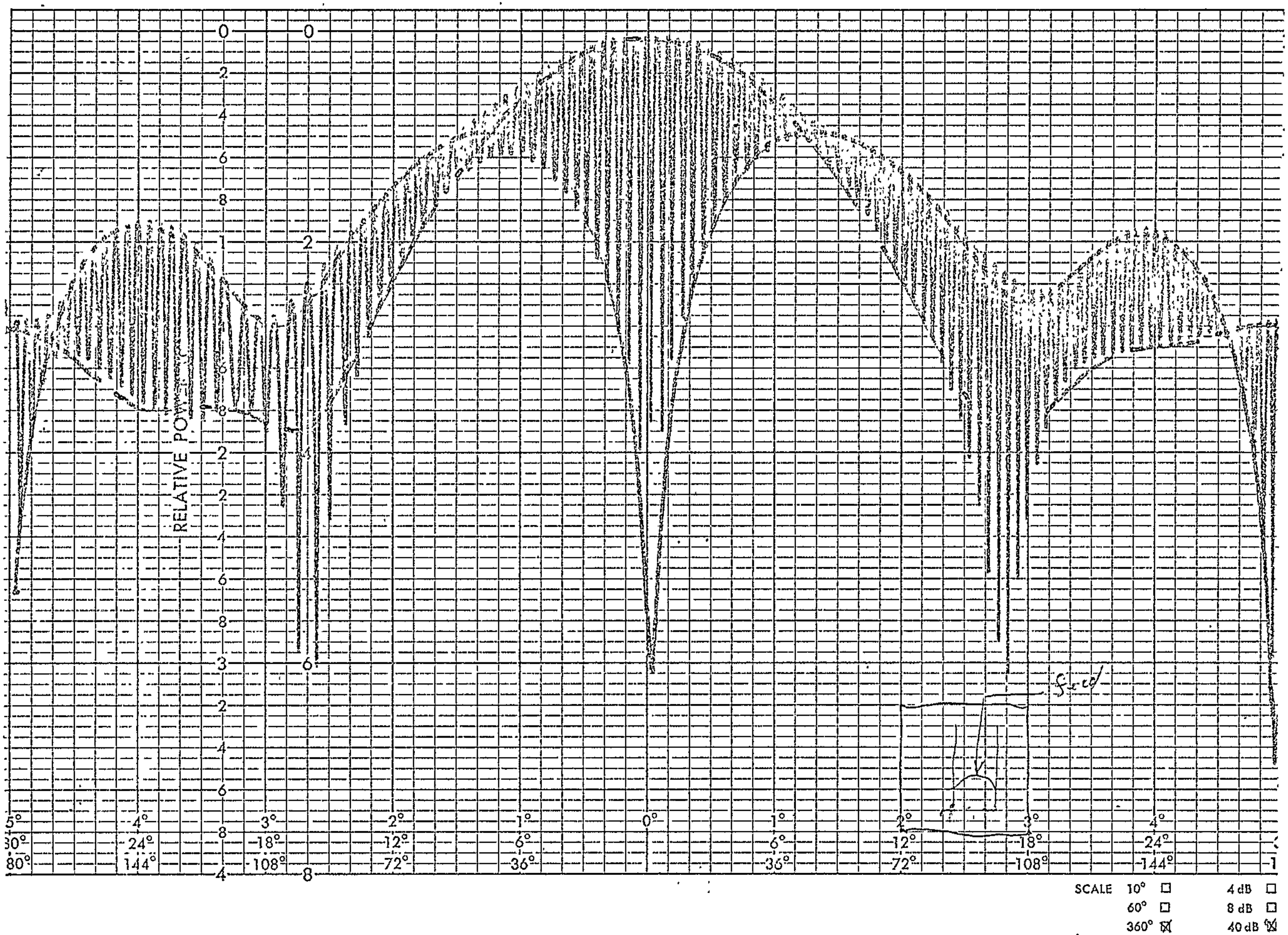


Figure 60. Pattern of Two Fins Spaced λ/4 Apart,
Fed In Phase, Rotating Polarization

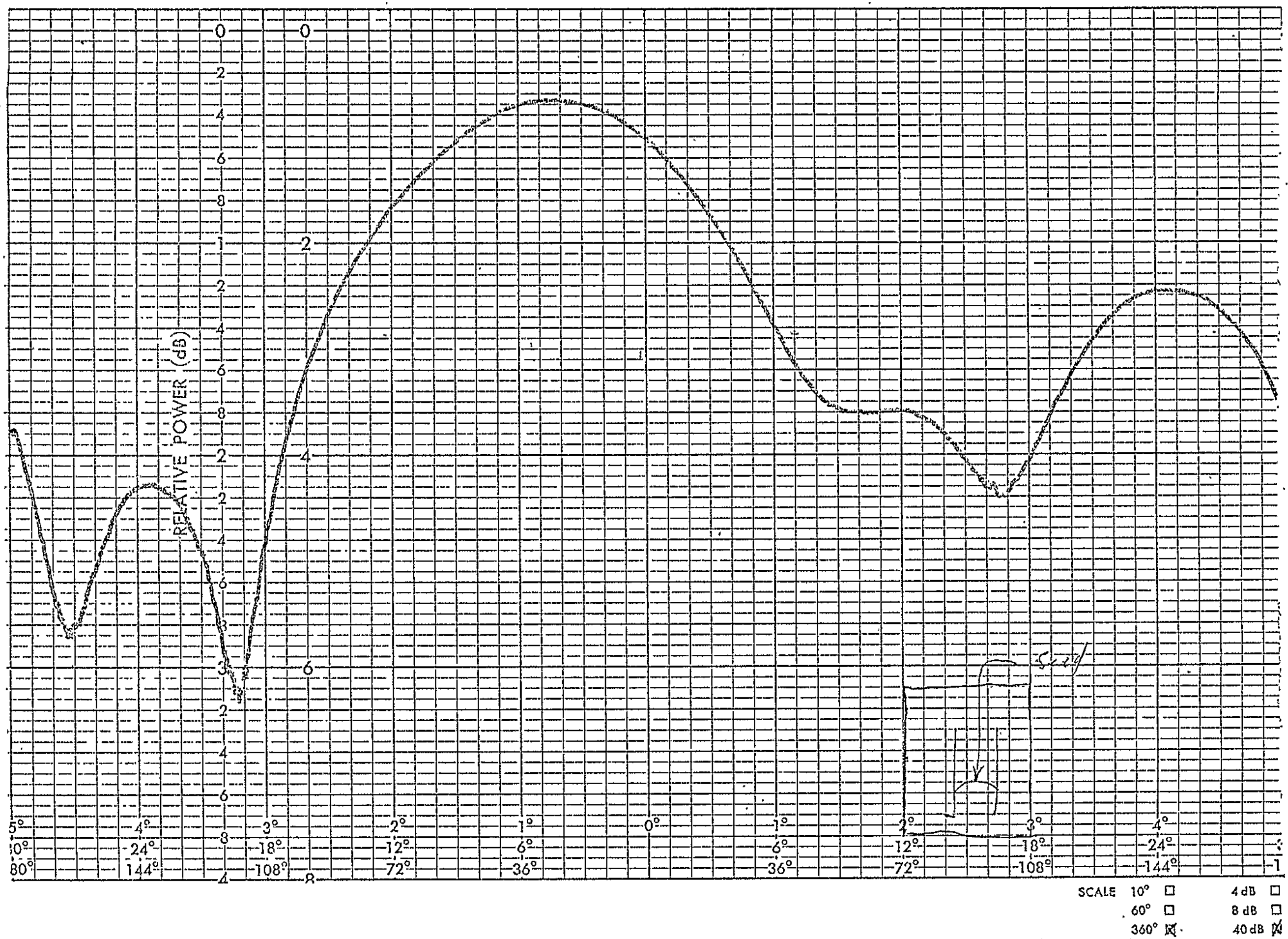


Figure 61. Pattern of Two Fins Spaced $\lambda/4$ Apart, Fed In Phase, Circular Polarization

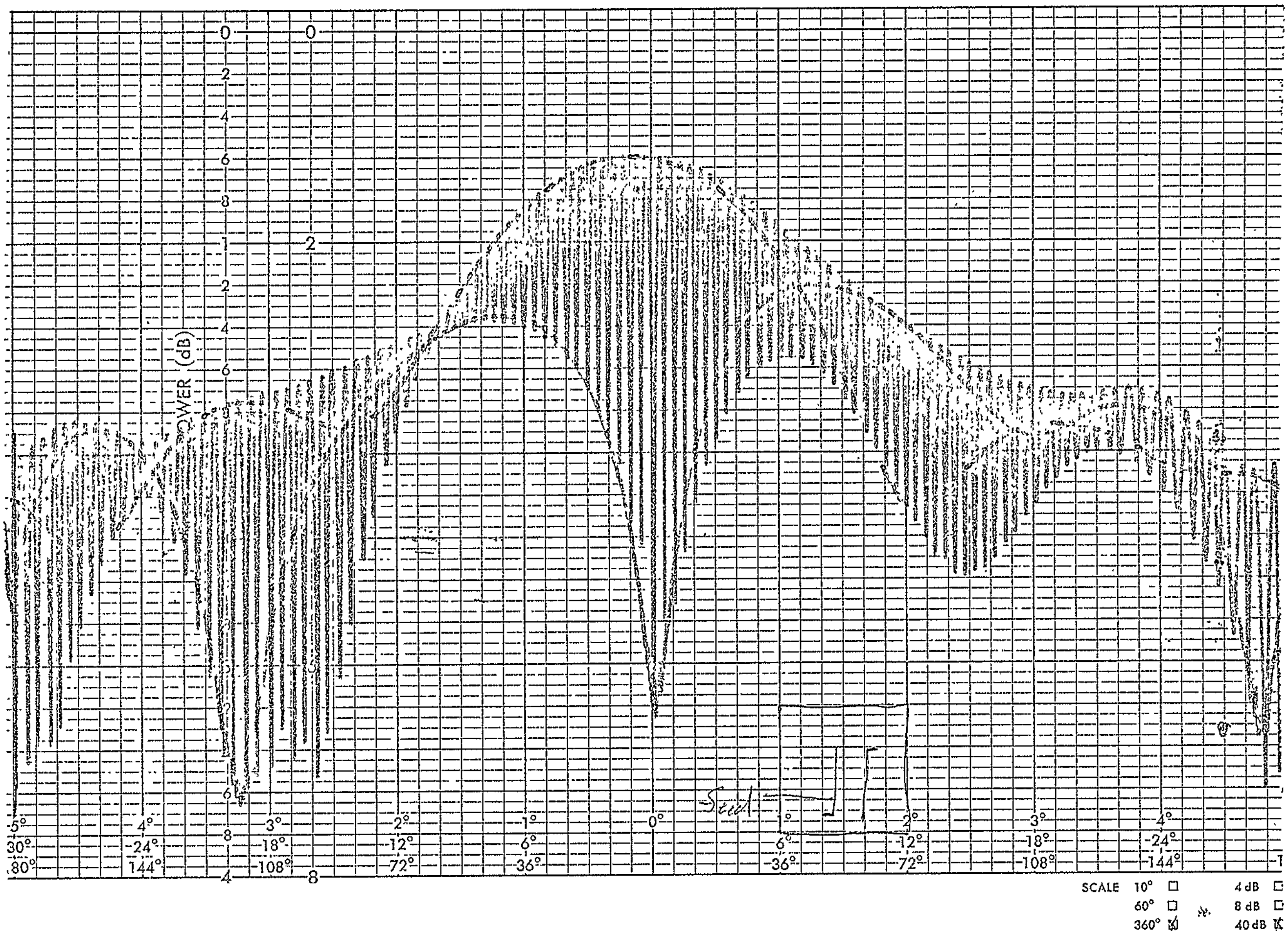


Figure 62. Pattern of Two Fins Spaced λ/4 Apart, and Reversed Rotating Polarization

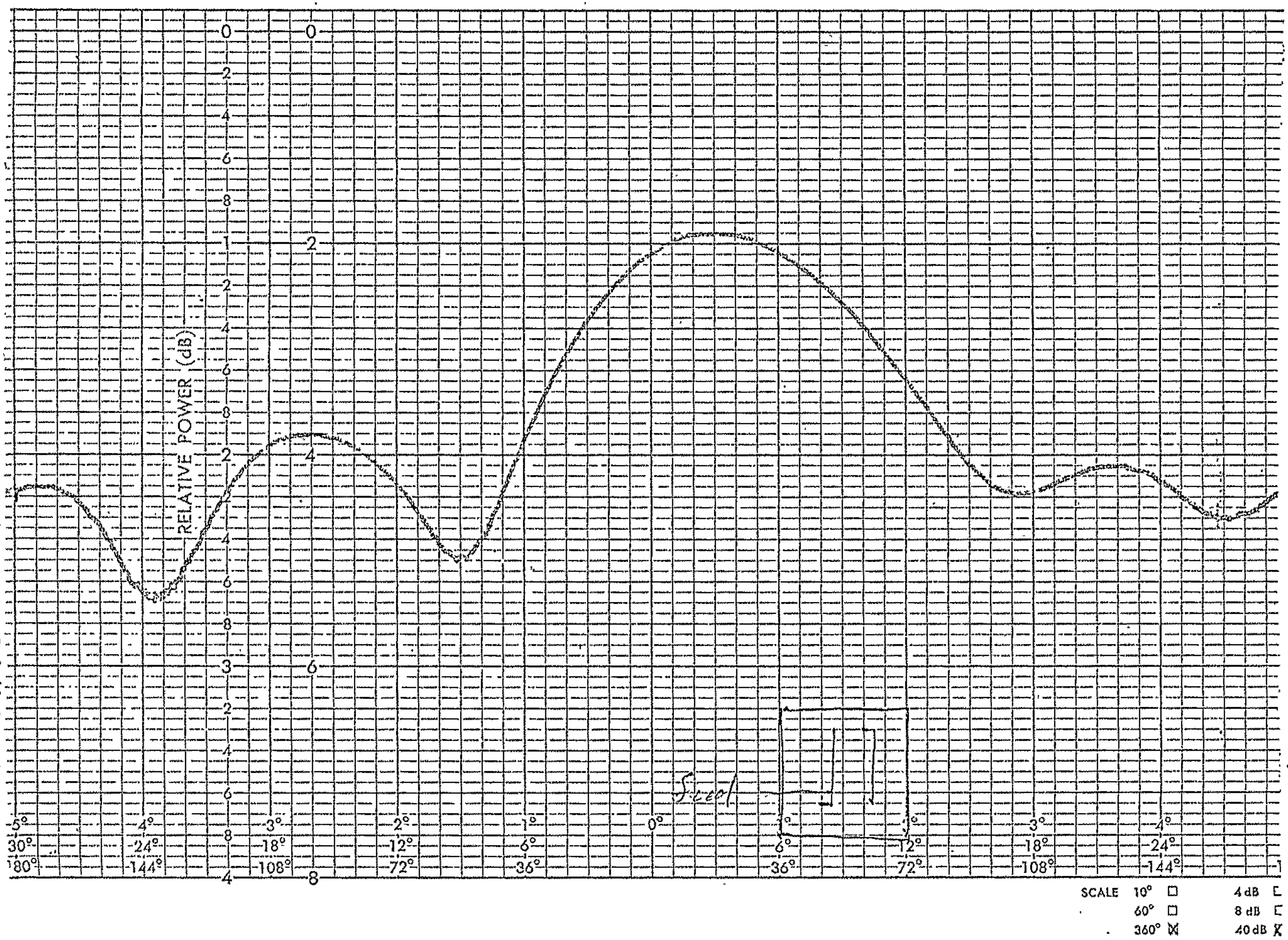


Figure 63. Pattern of Two Fins Spaced λ/4 Apart, and Reversed, Circular Polarization

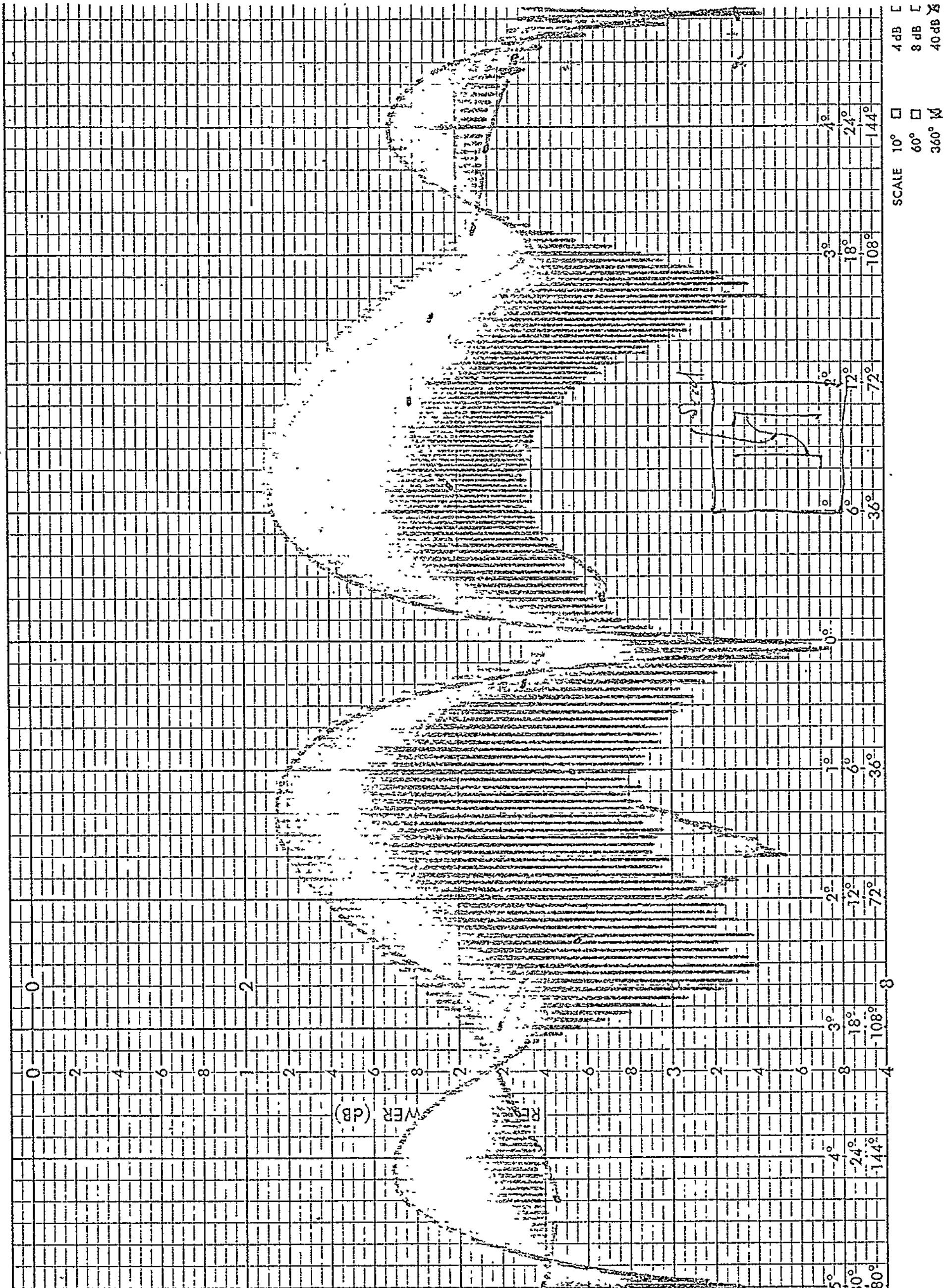


Figure 64. Pattern of Two Fins Spaced $\lambda/4$ Apart and Reversed, Fed in Phase, Rotating Polarization

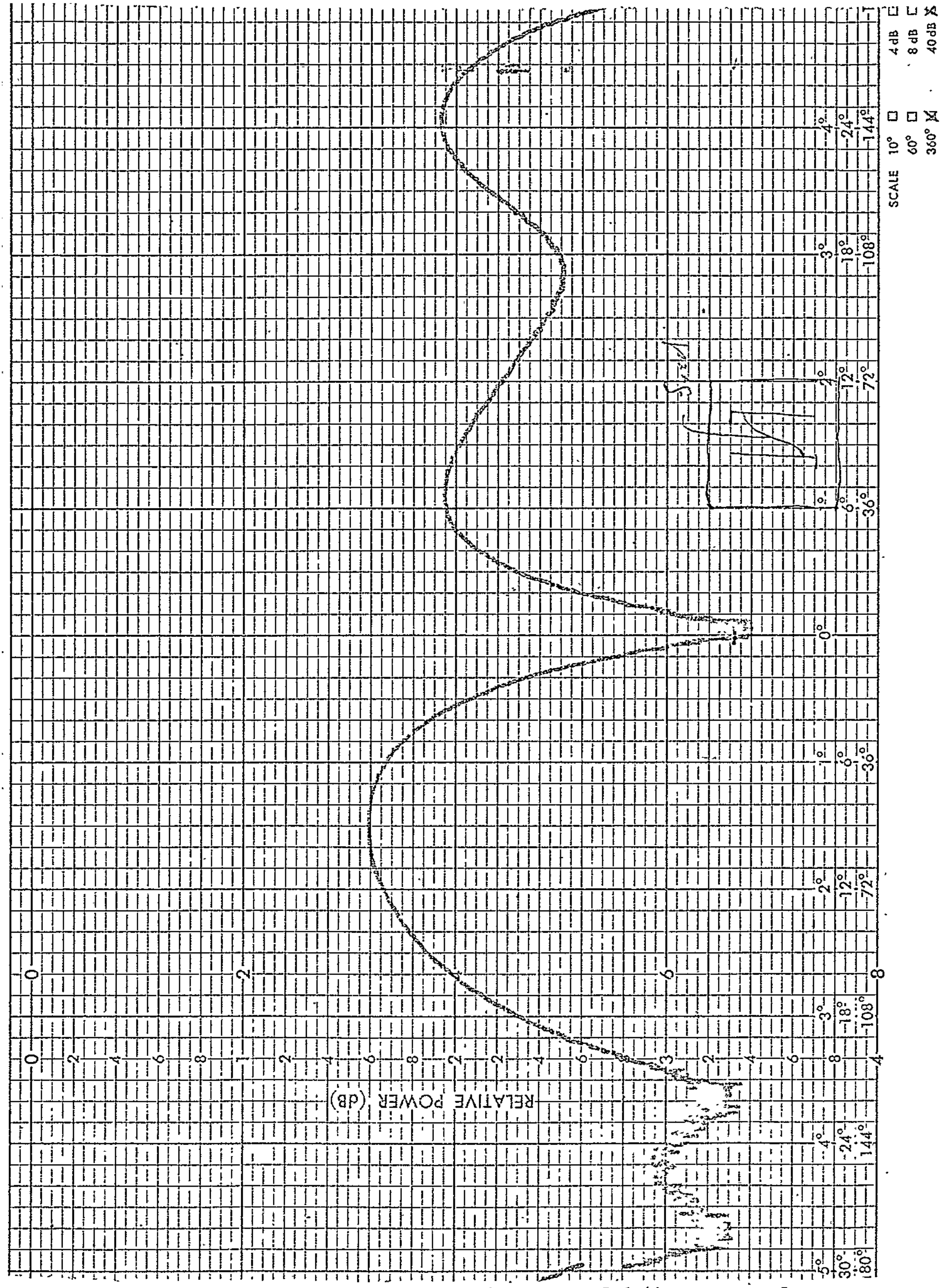


Figure 65. Pattern of Two Fins Spaced $\lambda/4$ Apart and Reversed, Fed in Phase, Circular Polarization

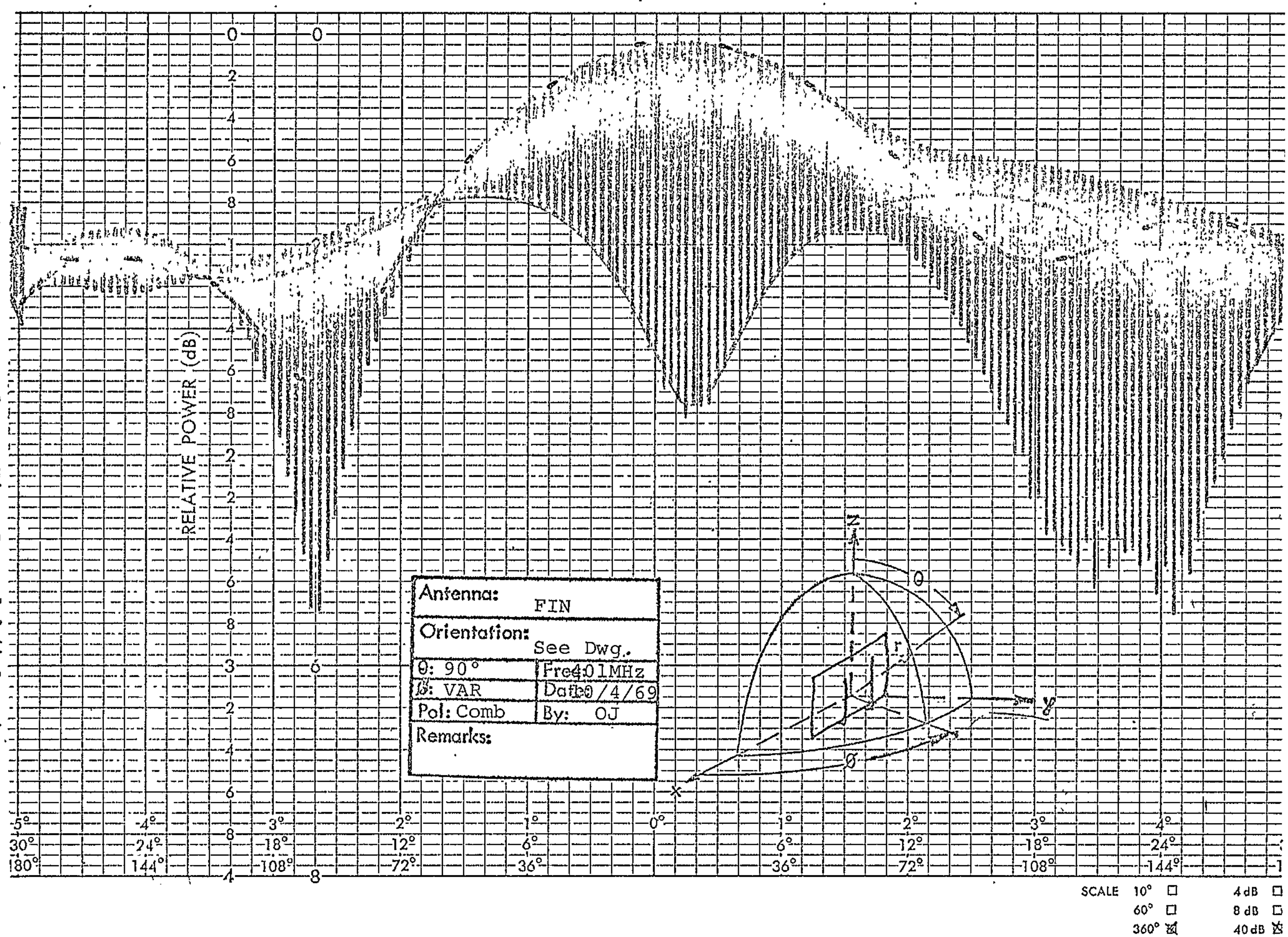


Figure 66. Pattern of Two Fins Spaced λ/4 Apart, 401 MHz, Rotating Polarization

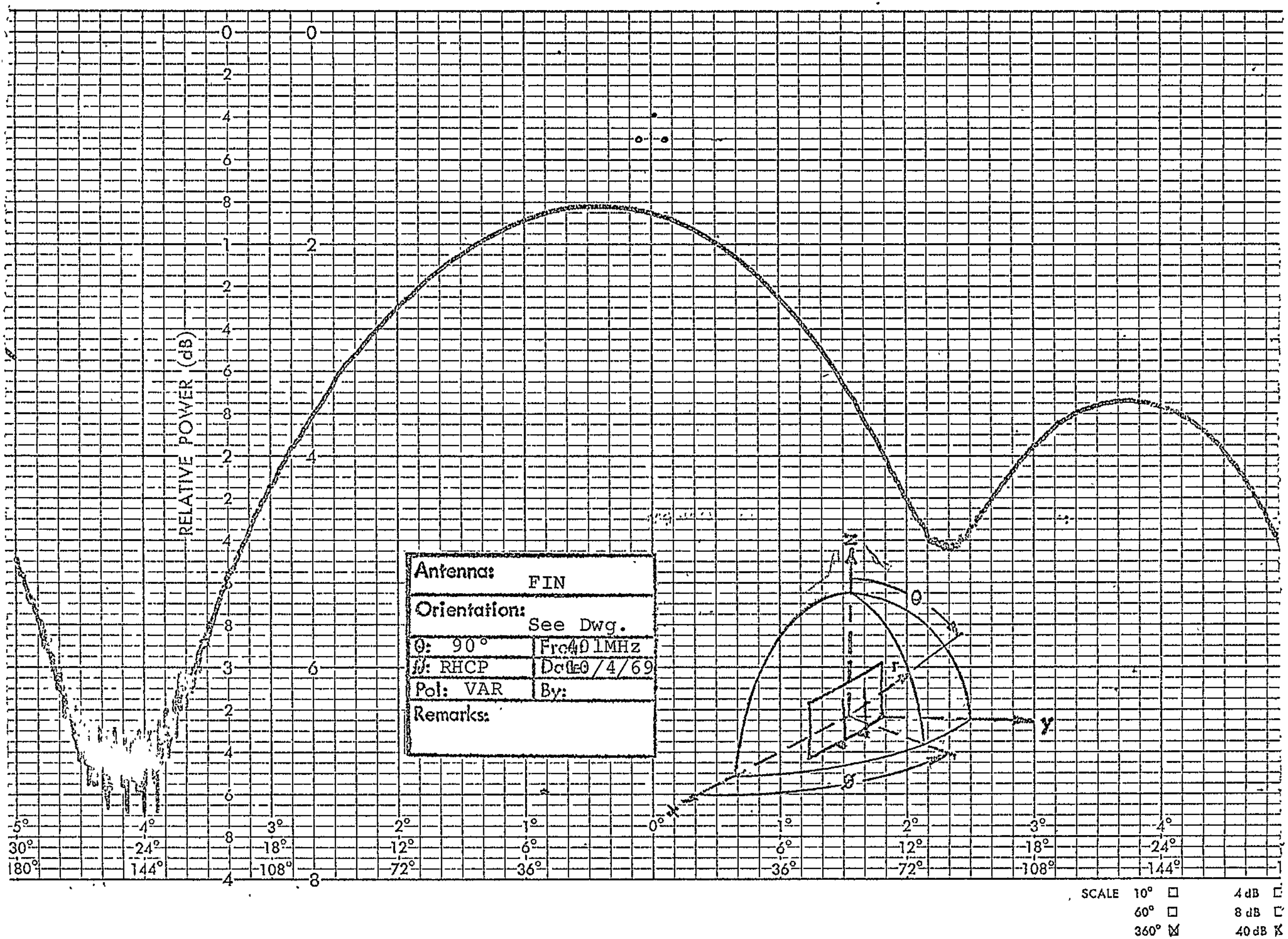


Figure 67. Pattern of Two Fins Spaced λ/4 Apart, 401 MHz, Circular Polarization

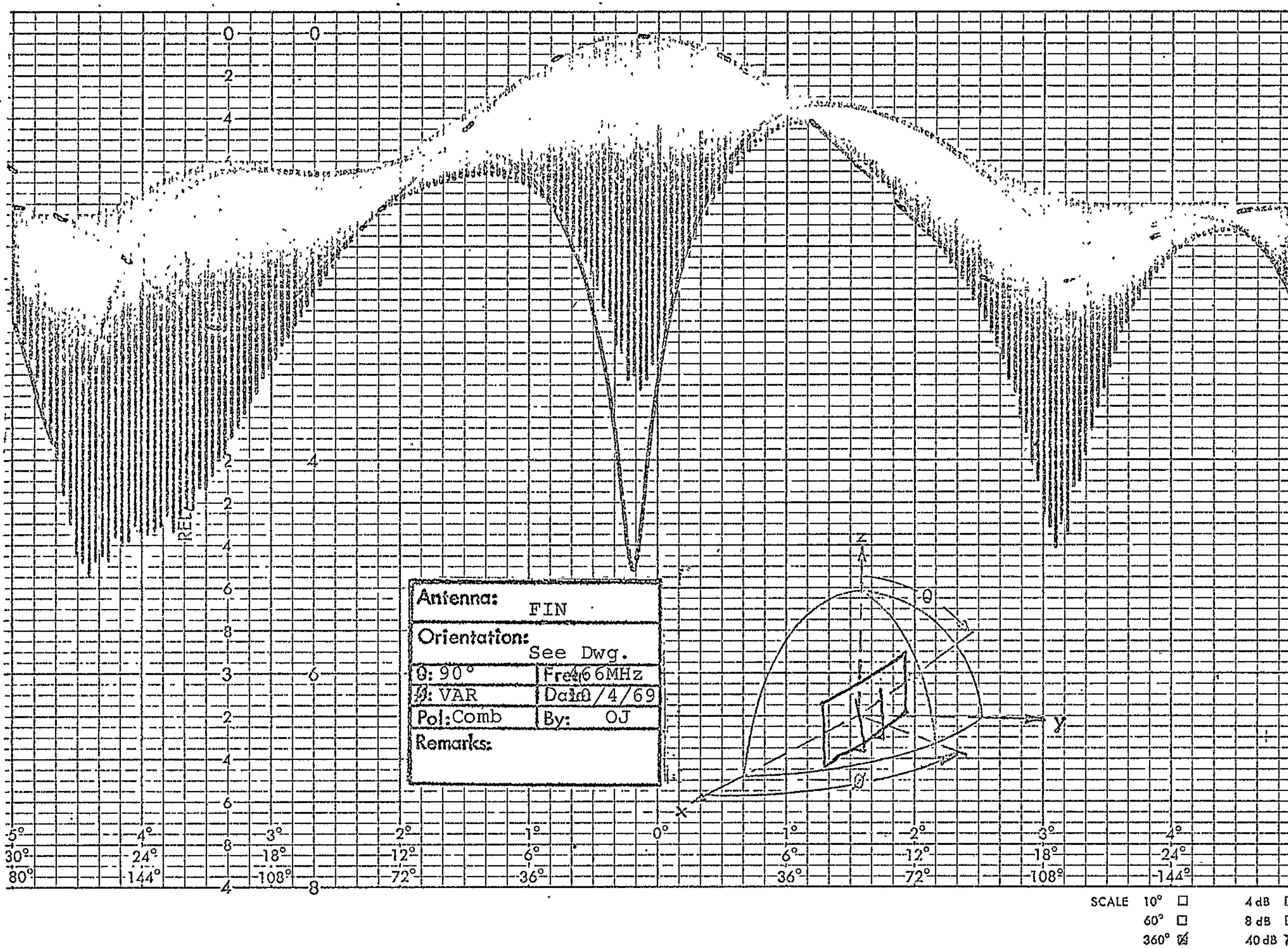


Figure 68. Pattern of Two Fins Spaced λ/4 Apart, 466 MHz, Rotating Polarization

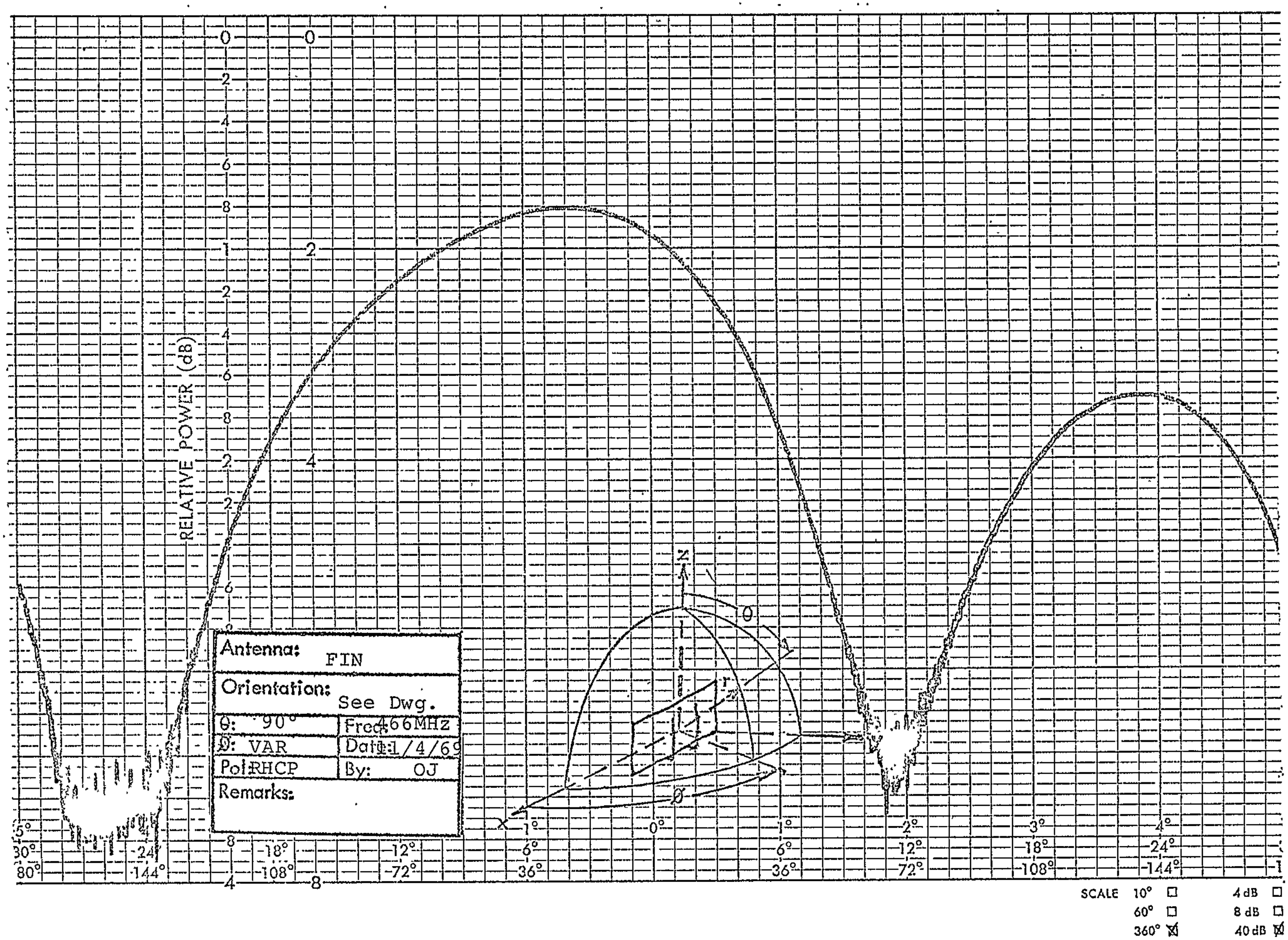


Figure 69. Pattern of Two Fins Spaced λ/4 Apart, 466 MHz, Circular Polarization

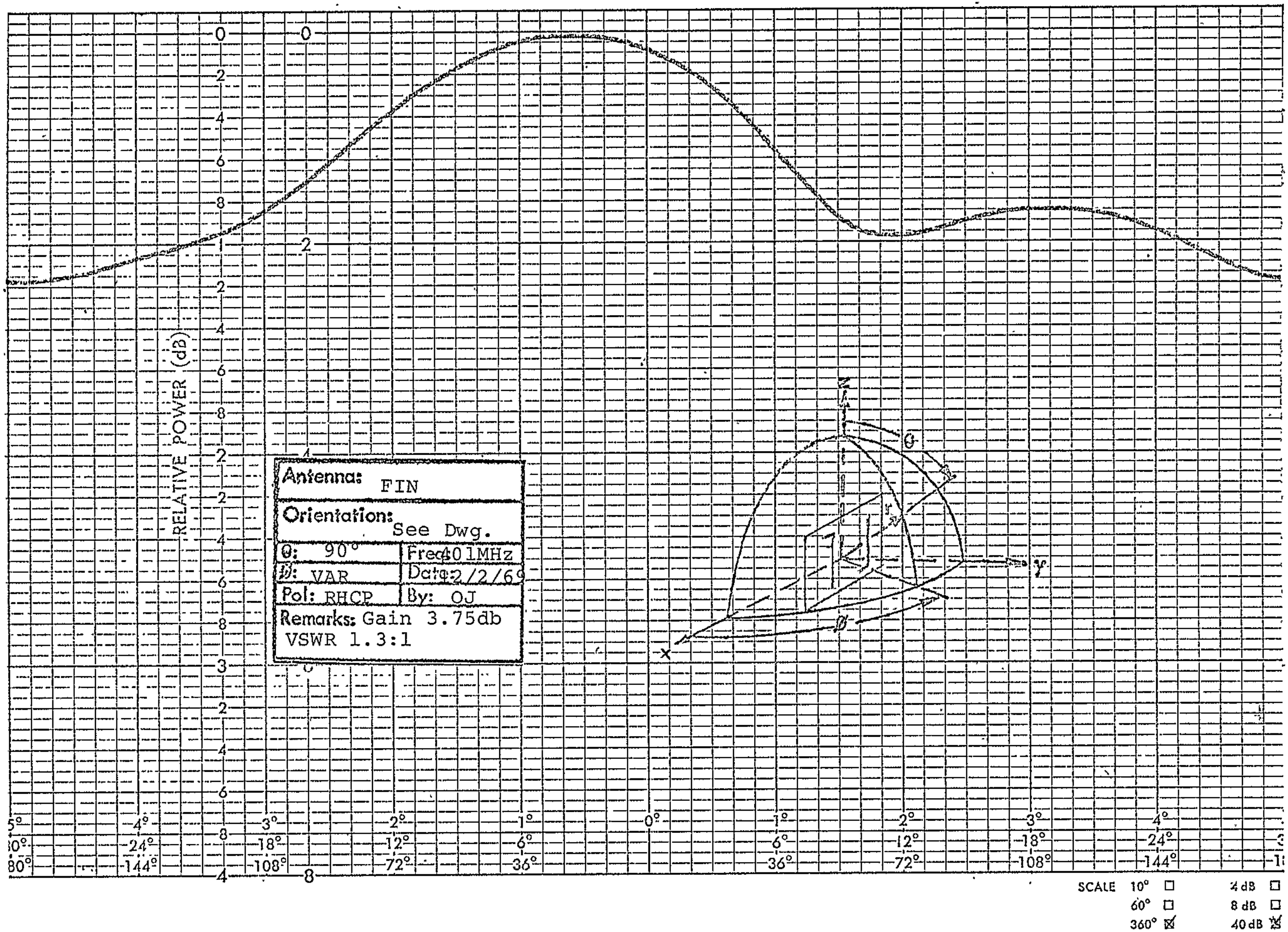


Figure 70. Pattern of Two Fins Spaced λ/4 Apart, Fins Reversed, 401 MHz Polarization

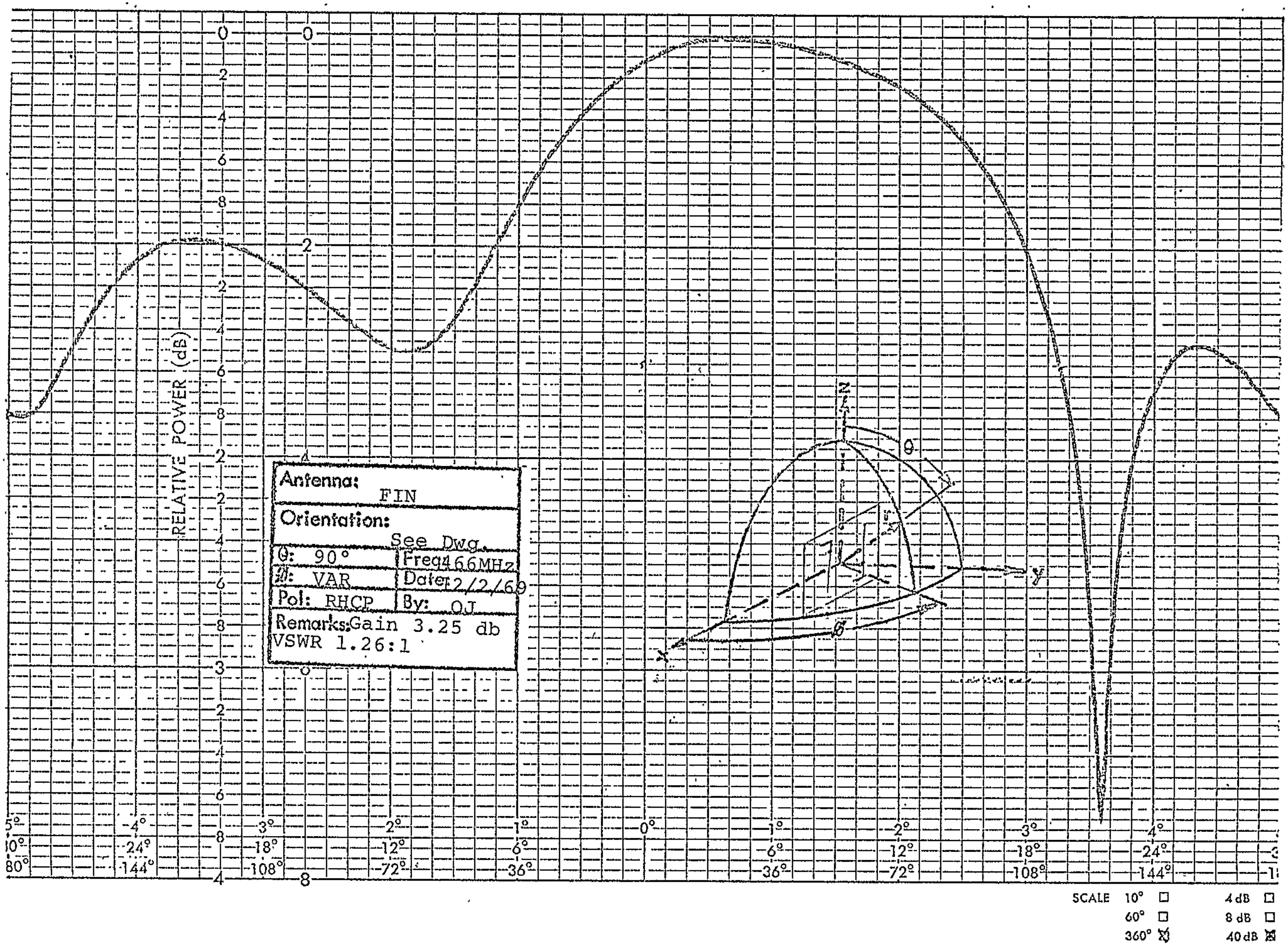


Figure 71. Pattern of Two Fins Spaced λ/4 Apart, Fins Reversed, 466 MHz Polarization

3.0 MECHANICAL DEVELOPMENTS

The final engineering model fin antenna consisted of two fins designed for the two operating frequencies. These fins were fabricated out of RG-52U brass X-band waveguide hard soldered to an epoxy-fiberglass double-sided printed circuit board which serves as a groundplane. The two fins are fed by semiridged coaxial cable and a teepower divider. The fin slot is filled with a teflon dielectric bar. This structure is painted to resist corrosion and an epoxy bead is placed on the ground-plane edges to eliminate the possibility of scratching the animal. Anidized aluminum mounting plates shaped to conform to the present animal harness are bolted to the groundplane. A sketch of this configuration is shown in Figure 72. A photograph of this antenna without the mounting plates is shown in Figure 1. The holes for attaching the mounting plates are visible in Figure 1.

It would be possible to construct the antenna entirely out of aluminum with some small savings in weight. However, this would require a dip brazed type fabrication technique which would be more expensive and time consuming. Lightening techniques should be considered if a weight reduction is necessary. The antenna in its present brass configuration weighs 1.76 pounds.

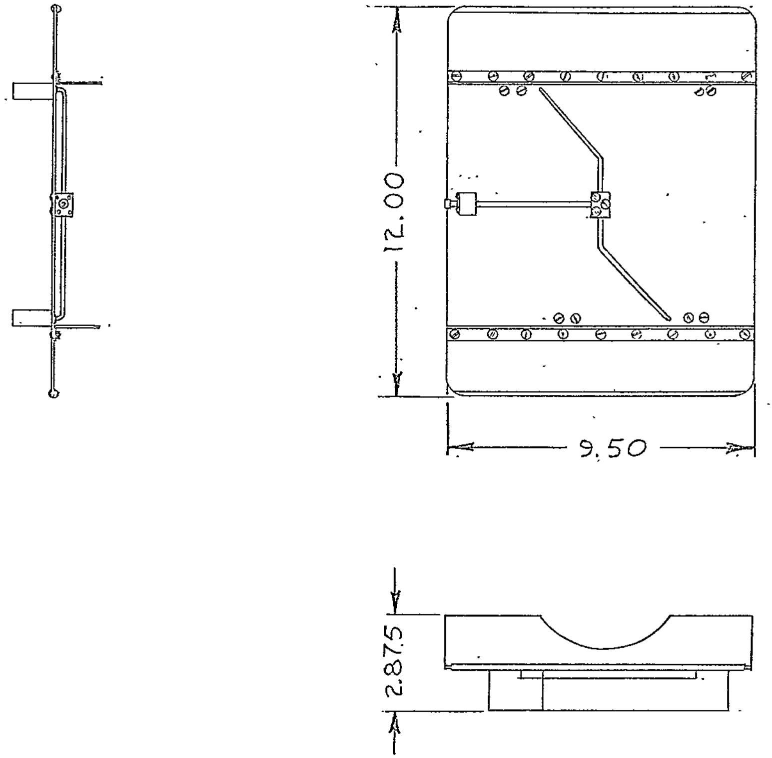


Figure 72. Sketch of Engineering Model

4.0 RESULTS AND CONCLUSIONS

Following successful test of the prototype antenna, an engineering model antenna was fabricated and tested. Figure 1 is a photograph of this antenna. The results for the engineering model are shown in Figures 73 and 77. The patterns at 401 MHz are given in Figures 73 and 74 and the patterns at 466 MHz are given in Figures 75 and 76. The impedance is shown in Figure 77. The engineering model was successfully interrogated at Goddard Space Flight Center by the Nimbus satellite.

It should be noted that the antenna performance is optimized for the animal application. It is designed to be small and rugged.

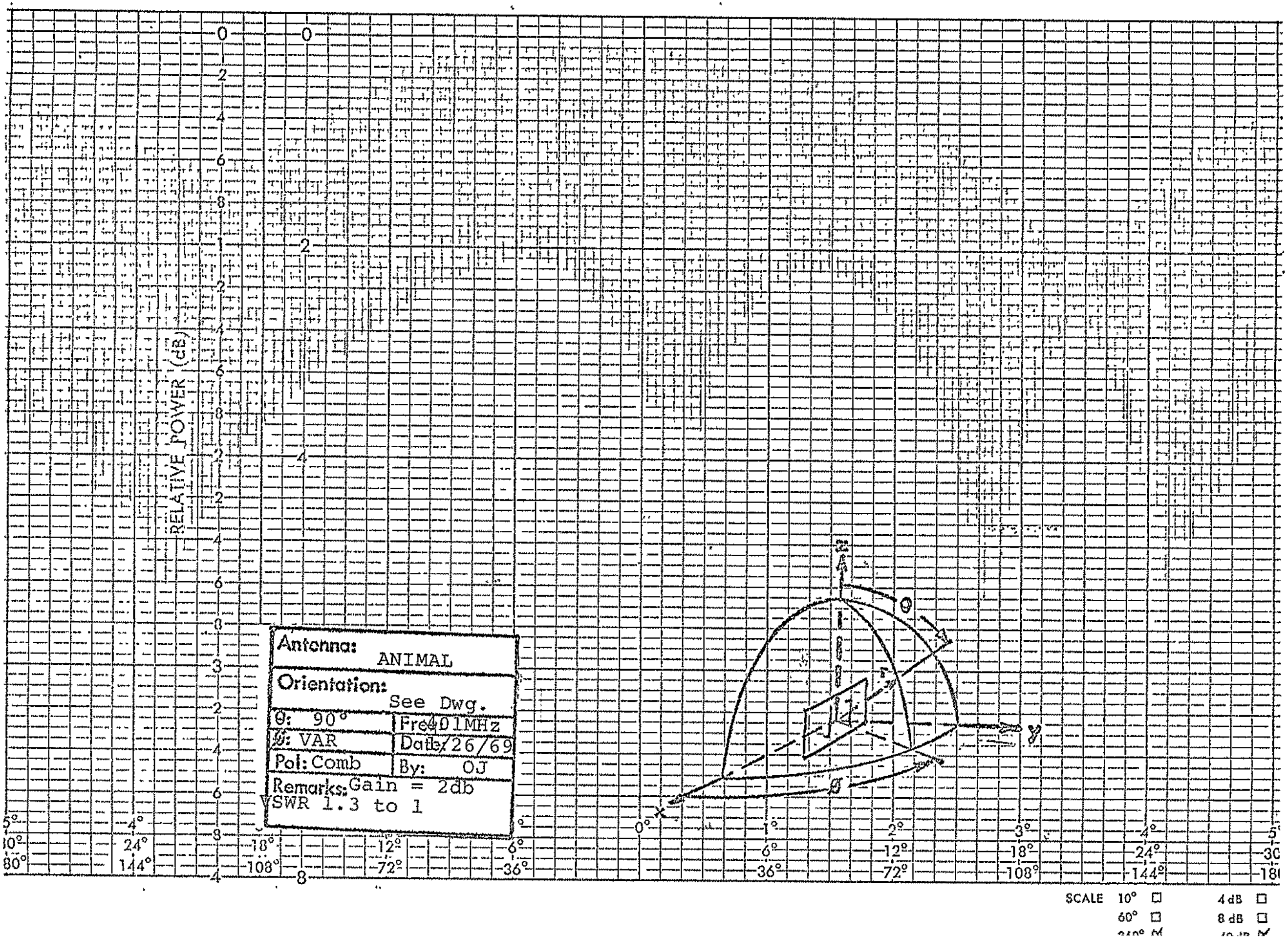


Figure 73. Pattern of Engineering Model, 401 MHz
Rotating Polarization

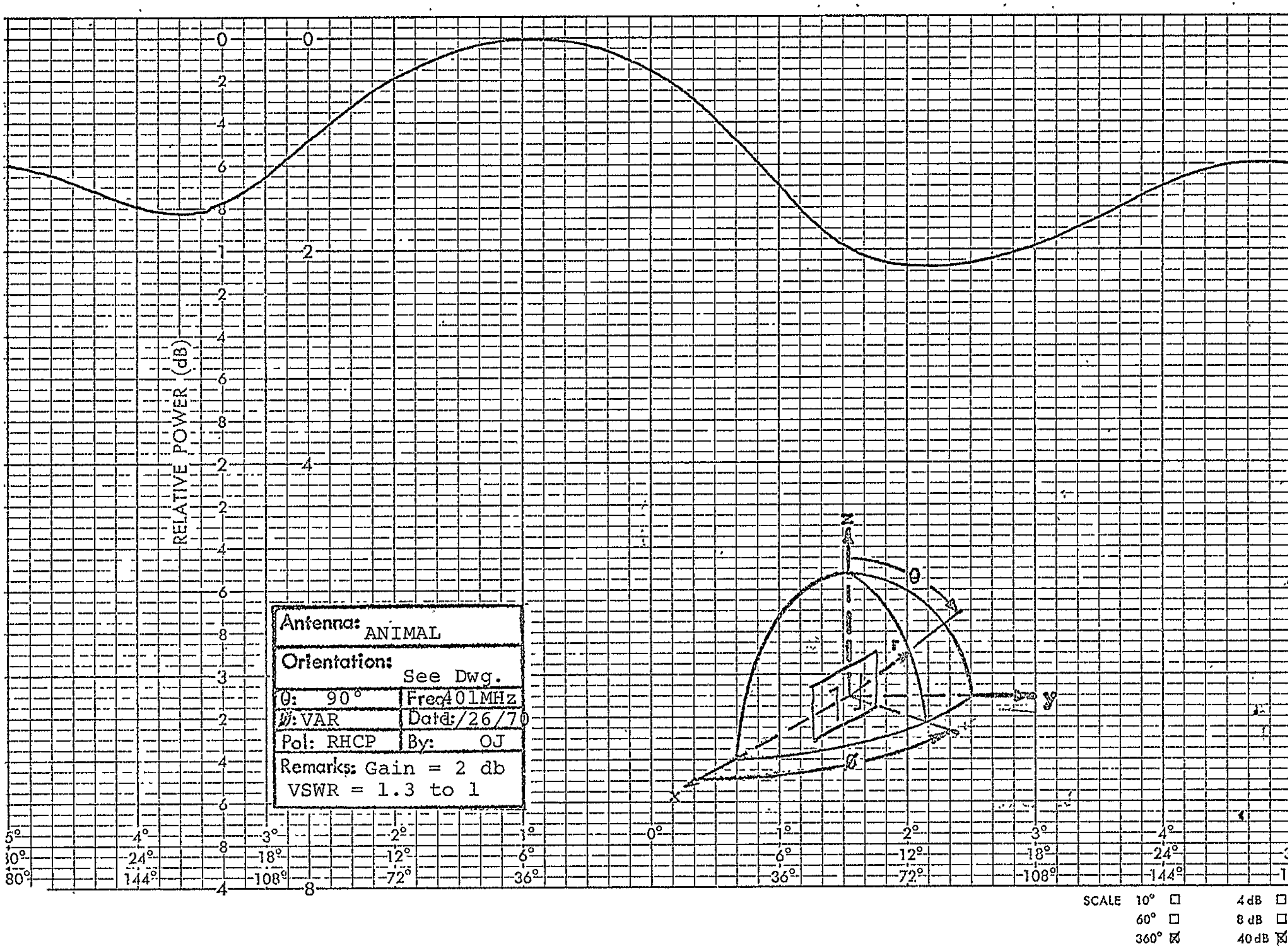


Figure 74. Pattern of Engineering Model, 401 MHz
Circular Polarization

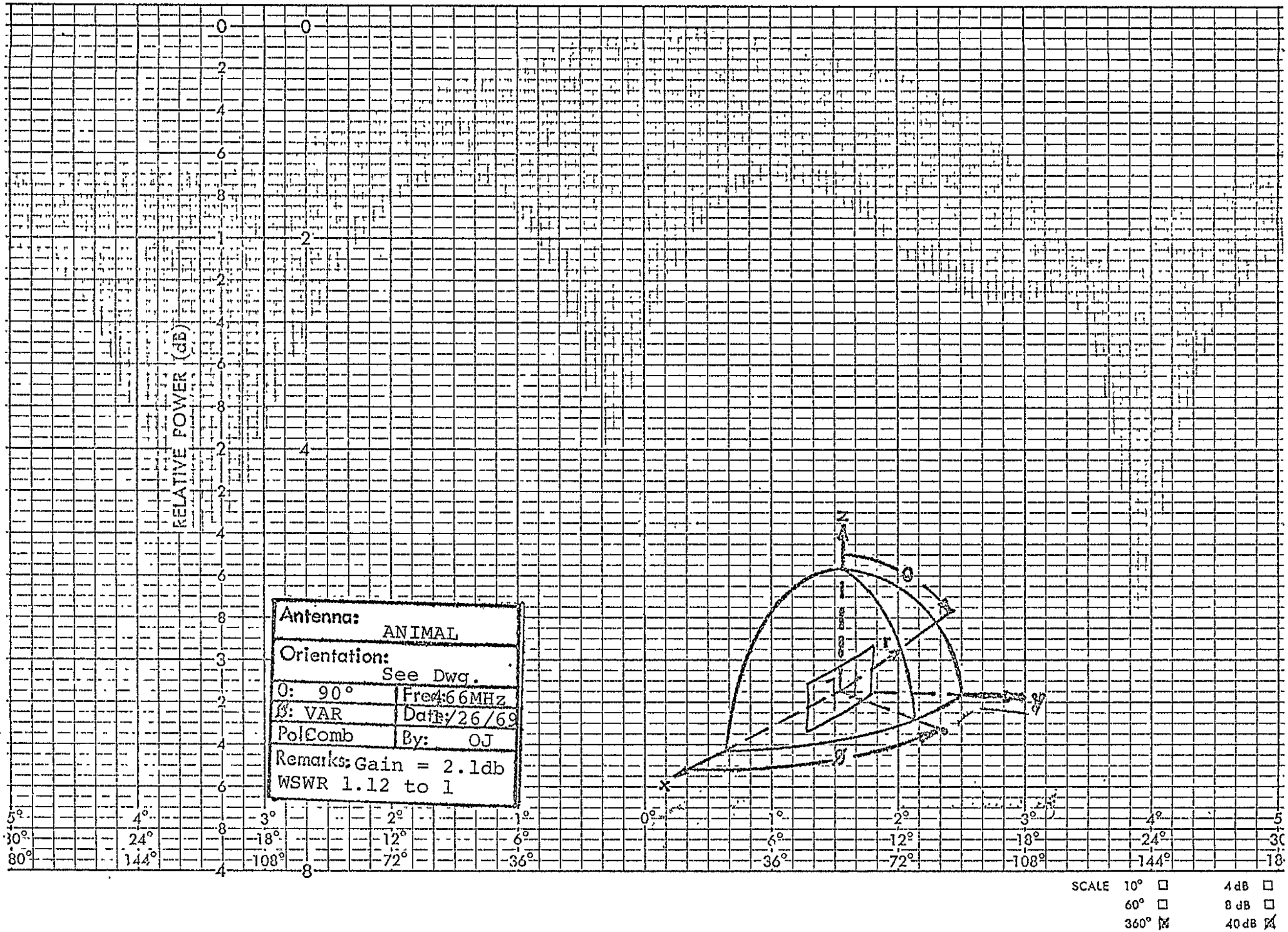


Figure 75. Pattern of Engineering Model, 466 MHz
Rotating Polarization

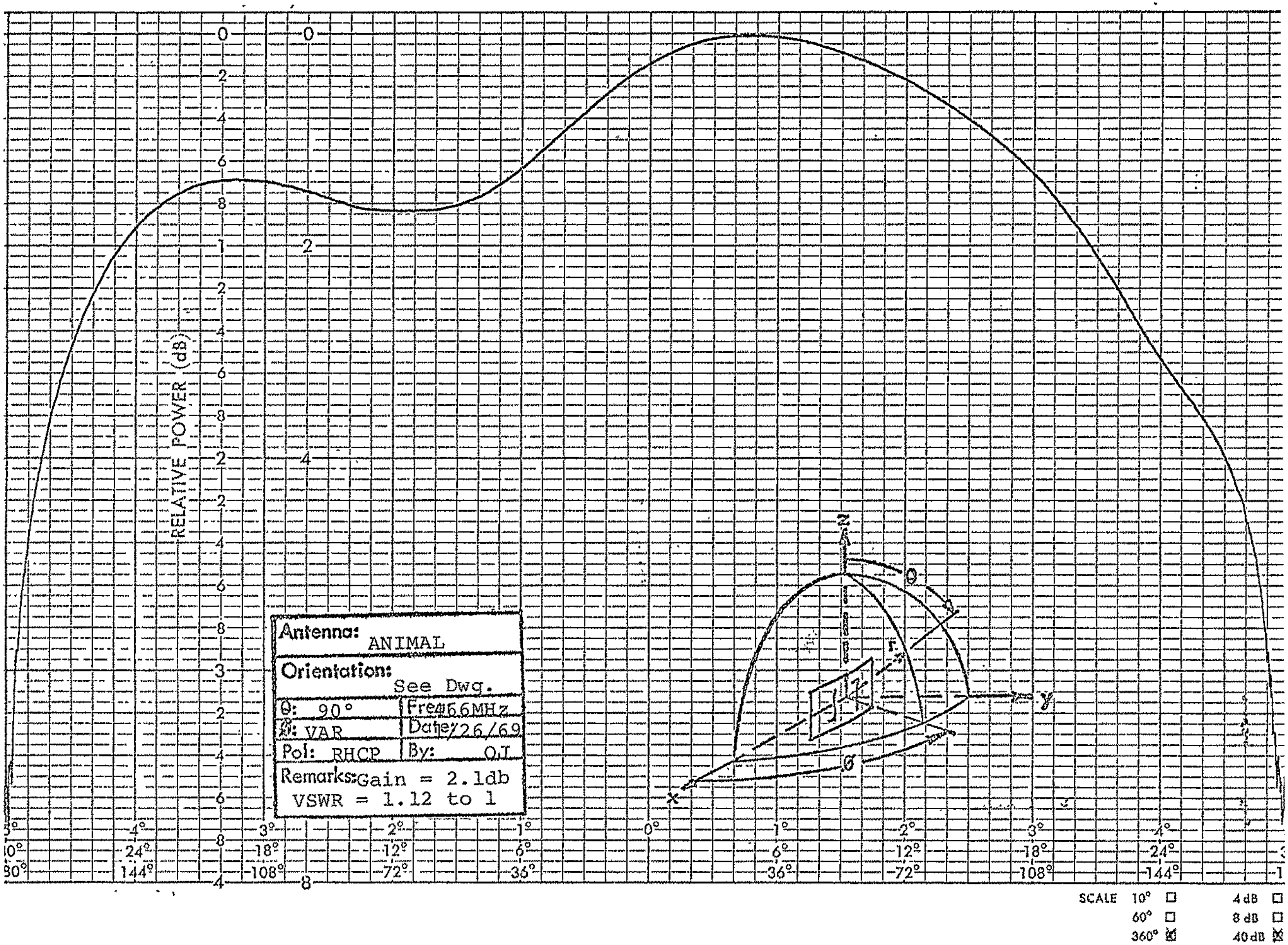


Figure 76. Pattern of Engineering Model, 466 MHz
Circular Polarization

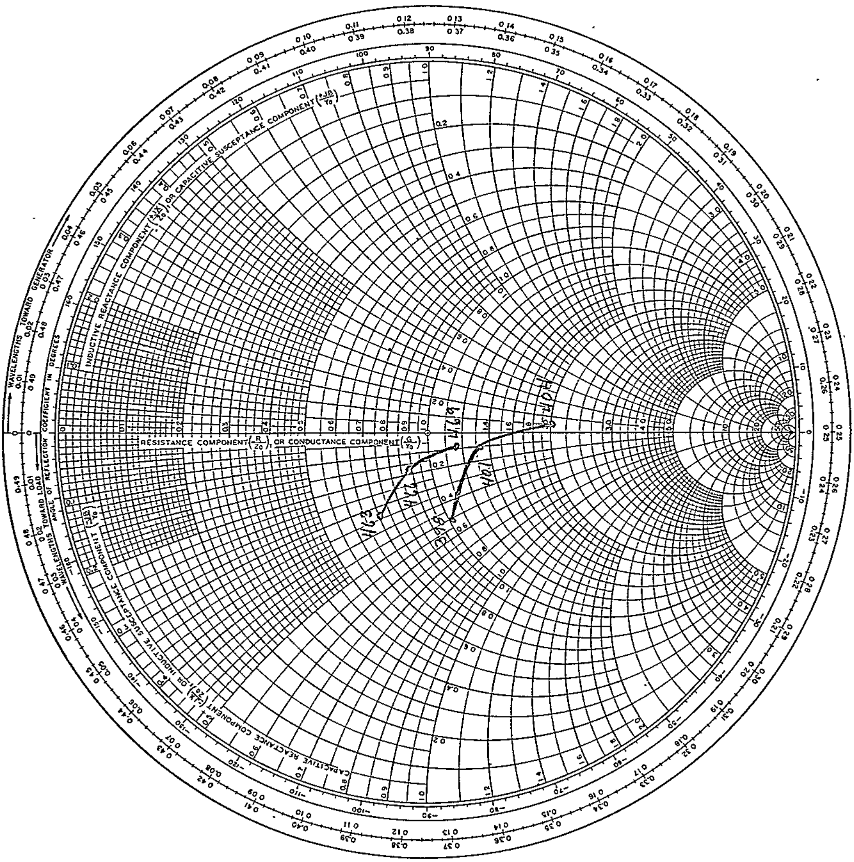


Figure 77. Impedance of Engineering Model

5.0 NEW TECHNOLOGY

The development work was monitored by the Project Engineer on a continuing basis in an effort to identify items of new technology realized under this contract.

The only development regarded as new is the actual fin configuration developed and delivered. The only thing new about this antenna is the adjustment made in the antenna parameters to optimize the performance when used in conjunction with a satellite interrogated animal package.

This final report documents this development in detail.

APPENDIX

THEORY OF OPERATION

The Fin antenna is a special case of a transmission line antenna[1] The geometry of the Fin antenna is shown in Figure A1. The horizontal antenna groundplane is located in the X-Y plane. The vertical Fin is located in the Y-Z plane.

The Fin antenna is fed with a coaxial cable from beneath the groundplane. The outer conductor of the cable is attached to the groundplane and the inner conductor is attached to the horizontal portion of the fin a short distance from the fin vertical support. This feeding arrangement produces a voltage across the slot in the Z direction and a current along the fin producing a voltage in the Y direction. These two voltages are dispalced by 90° in phase.

The far fields of the fin are given approximately by

$$E_z \simeq E_o \sin \Theta \cos\phi, \tag{A1}$$

$$E_y \simeq jE_o \cos \Theta \cos \phi . \tag{A2}$$

The 90° time and space displacement of these two fields produces circular polarization. The fields of Equations A1 and A2 produce a transmitted wave whose polarization vector rotates in a clockwise direction when looking from the fin antenna in the positive X direction and produces a polarization vector rotating in a counter-clockwise direction looking in the negative X direction. The radiation from this antenna is therefore right hand circularly polarized along the positive X axis and left hand circularly polarized along the negative X axis.

1. Wolff, E.A., Antenna Analysis, John Wiley & Sons, 1966. Section 3.12 pages 103-108.

An enlarged cross section view of the fin antenna is shown in Figure A2 and the equivalent circuit is shown in Figure A3. Equations for the radiation resistance and input reactance for a fin with a circular cross section are given in the literature.[2] They are not directly applicable to the rectangular cross section of this antenna.

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2. Ibid.

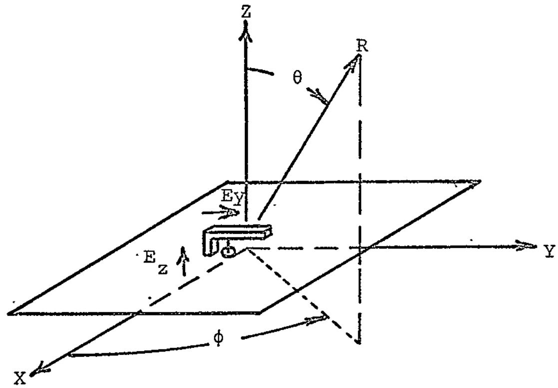

Figure A1. Geometry of Fin Antenna

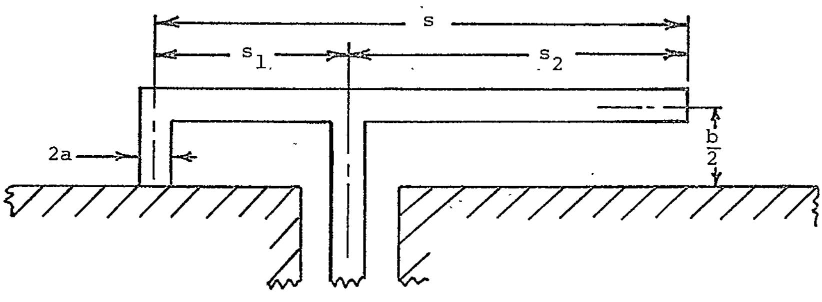

Figure A2. Fin Antenna Cross Section

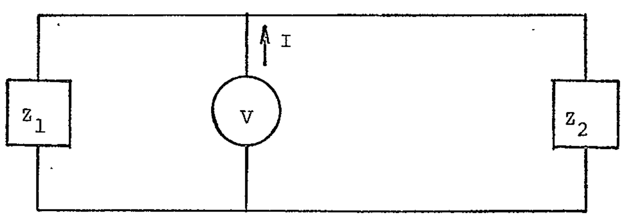

Figure A3. Equivalent Transmission Line Circuit for Fin Antenna